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Distribution and demographics of marine mammals in SOCAL through photoidentification, genetics, and satellite telemetry

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DISTRIBUTION AND DEMOGRAPHICS OF MARINE MAMMALS IN SOCAL THROUGH PHOTO-IDENTIFICATION, GENETICS, AND SATELLITE TELEMETRY

by

Erin A. Falcone and Gregory S. Schorr

December 2014

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Prepared for: Chief of Naval Operations
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14. ABSTRACT
This report summarizes data collected during small-vessel surveys for cetaceans in the Southern California Bight (SCB), with a focus on the Southern California Offshore Range Complex (SCORE), from June 2010-January 2014. Detailed annual progress reports were prepared after each survey year through 2013 and are available online through the Naval Postgraduate School. This final report emphasizes analyses that combine data across study years, particularly with respect to two focal species: Cuvier's beaked (*Ziphius cavirostris, Zc*) and fin (*Balaenoptera physalus, Bp*) whales. 18 cetacean species were encountered in surveys based at SCORE, and several previously documented seasonal trends in species occurrence were confirmed. *Bp* were sighted in every month surveyed, *Zc* in all but one, suggesting both are present year-round. Preliminary mark-recapture abundance estimates from photo-identification data suggest both species have local populations in the low hundreds. Both photo-identification and telemetry data suggest *Zc* exhibit a degree of basin-specific site fidelity within the SCB. Many *Bp* also appear to preferentially remain within the SCB year-round, with increased use of nearshore waters in fall and winter. A subset of 688 hours of Zc diving behavior from periods without Mid-Frequency Active Sonar use in the area showed that the behavior of these whales was similar to that of the larger dataset (including sonar exposure), and confirms previous observations that *Zc* here appear to forage less often than whales in other regions, and that sonar exposure is unlikely to be the primary driver of these regional differences, though some exposures may cause foraging disruption. Future research will seek to further elucidate the relationship between behavioral patterns and sonar use in the area.

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Marine mammals, cetaceans, photo-identification, satellite tagging, location data, diving data, Cuvier's beaked whales, fin whales, Southern California Bight, SOAR, SCORE

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Summary

This report summarizes data collected during small-vessel surveys for cetaceans in the Southern California Bight (SCB), with a focus on the Southern California Offshore Range Complex (SCORE), from June 2010 through January 2014. Detailed annual progress reports were prepared following each survey year through 2013 and are available online through the Naval Postgraduate School. Therefore, this final report will primarily serve to summarize the complete set of data collected from 2010-2014. We present results of analyses that include data across all grant years, and in some cases incorporate data from earlier years, for two focal species: Cuvier's beaked whales (*Ziphius cavirostris, Zc*) and fin whales (*Balaenoptera physalus, Bp*).

Introduction

The SCB is renowned for both the density and diversity of marine life it supports. More than 20 species of cetacean occur in the region. Some are present year-round, while others are seasonal migrants, passing through or present in larger numbers at certain times of year. While numerous studies have focused on species that are common along the populous coastal areas, there have been few dedicated studies of cetaceans in the outer waters of the Bight that lie to the south and west of the Channel Islands.

Until recently, this has been particularly true for the waters around San Clemente Island (SCI), the southernmost island off the California coast and also one of the furthest from the mainland. SCI is the center of the Southern California Offshore Range (SCORE), a complex of land, sea, and aerial training areas managed by the US Navy and heavily used by several branches of the military. Due to both its distance from shore and its often restricted status, few dedicated vessel-based visual surveys for cetaceans have been conducted there. While the Navy is authorized to use mid-frequency active sonar (MFAS) anywhere within the larger Southern California Range Complex (SOCAL), it is used most often in the San Nicolas Basin, which lies west of SCI. This basin contains the Southern California Anti-submarine Warfare Range (SOAR), a broad, multi-sensor hydrophone array where exercises including the use of MFAS occur regularly (Figure 1). Given the sensitivity of some cetacean species to MFAS elsewhere (e.g., see Cox *et al.* 2006 and D'Amico *et al.* 2009), a detailed study of cetacean populations and habitat use in this area was warranted.

Thus, this study was initiated in 2010 after several successful pilot surveys in the preceding years identified SOAR as potentially important habitat for two poorly studied species in the region: Cuvier's beaked whales (*Ziphius cavirostris, Zc*) and fin whales (*Balaenoptera physalus, Bp*). Through an ongoing partnership with the Naval Undersea Warfare Center's (NUWC) Marine Mammal Monitoring on Ranges (M3R) program (Moretti *et al.* 2006), we have been able to collect some of the first detailed information on the demographic status and distribution of these and other species around SCORE using photo-identification and satellite telemetry.

Photo-identification studies have proven invaluable in defining the population size and structure and movement patterns of a variety of cetacean species in Southern California, most notably blue and humpback whales (Calambokidis & Barlow 2004) and coastal bottlenose dolphins (Defran & Weller 1999). The use of photo-ID of *Zc* and *Bp* in the region has been limited prior to this study, due primarily to their offshore distribution and low and/or unpredictable sighting rates. Adult *Zc* are generally well-marked, and thus well-suited to photo-identification techniques provided an adequate sample of images can be obtained over time (Falcone *et al.* 2009), as is now the case with the advent of M3R at SOAR. Individual fin whales in this region, in contrast, are much more subtly marked. However, with good quality photographs it has been demonstrated that there is sufficient variation in the shape of the dorsal fin and marks on the fin and body to reliably identify most individuals over periods of at least several years, and for the more distinctive individuals, much longer (Falcone *et al.* 2011). Work at SCORE has supported the first regular collection of photographs from offshore aggregations of fin whales, which have been noted to occur more frequently in the outer waters of the SCB particularly in warmer months, when most previous cetacean surveys were conducted (Forney & Barlow 1998, Douglas *et al.* 2014). However, recent years have seen increasing numbers of fin whales in coastal mainland waters during winter months, and thus the sample of fin whale photographs for use in this study has been greatly augmented through the inclusion of opportunistic collections of photographs from other surveys by Cascadia Research Collective (CRC) and other local research organizations and naturalists.

While photographic methods can provide some insights into extra-regional movements, either through comparisons to catalogs from other areas or in some cases from the occurrence of geographically variable marks or parasites (Falcone *et al.* 2011), these results are inherently effort-biased and coarse. For this reason, satellite telemetry is an ideal complement to photo-identification. Tags deployed in this study provided unbiased movements records for tagged individuals over periods of weeks and months. This type of data can better characterize habitat use and residency patterns in areas of interest, such as around SCORE, much more robustly than visual surveys are able. Telemetry data also avoid the behavioral and geographic limits of passive acoustic data (where presence can only be determined within the instrumented range when animals are vocally active). Finally, the movements of tagged individuals can help to inform assumptions related to population range that underlie the statistical methods used to estimate population parameters from photo-identification data.

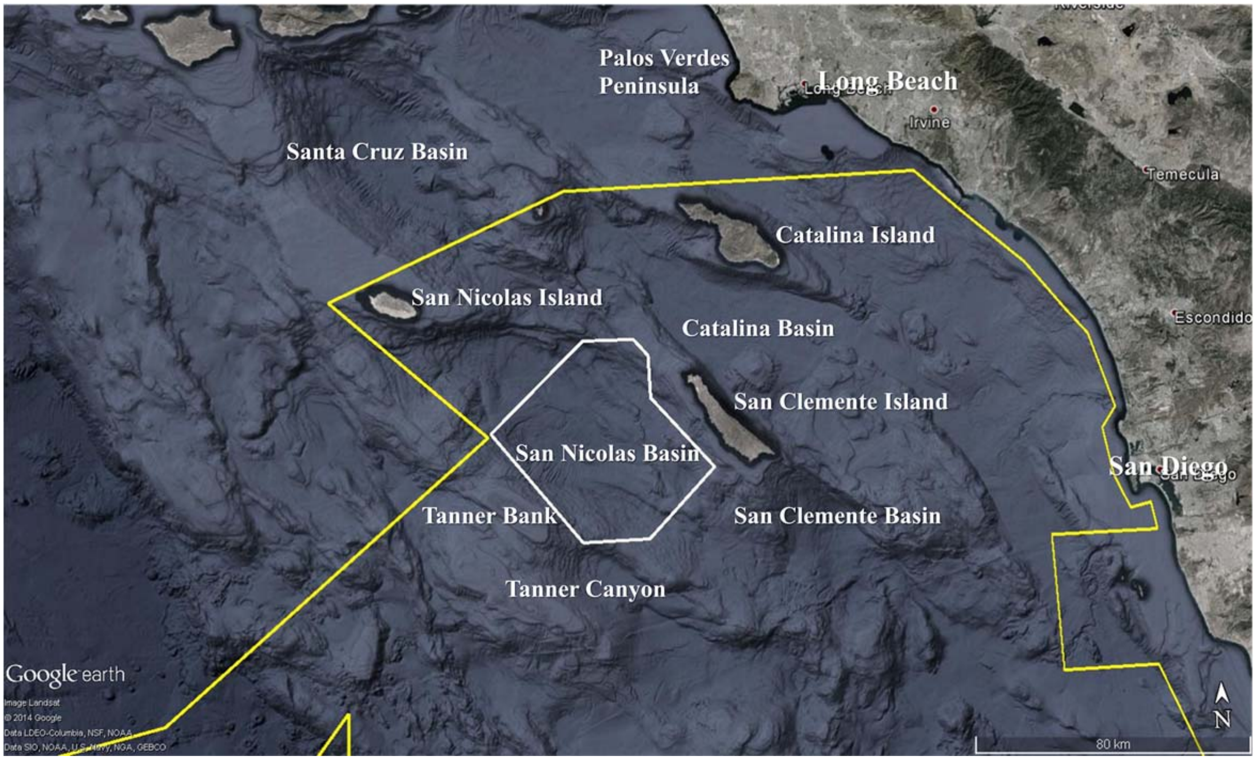


Figure 1. Map of the study area. The boundary of the Southern California Range Complex (SOCAL) is outlined in yellow, and the boundary of the Southern California Anti-submarine Warfare Range (SOAR) is outlined in white.

Methods

Field Data Collection

Surveys were conducted using a 6m rigid-hulled inflatable boat (RHIB) powered by two 75 hp outboard motors and equipped with a raised bow pulpit to facilitate tag deployments. The vessel was launched from a shore base each morning and surveyed throughout daylight hours as conditions permitted. Effort was apportioned in two ways: dedicated surveys in conjunction with visual verification tests of the M3R system at SOAR, and opportunistic surveys elsewhere in SOCAL during periods of favorable weather when range access was restricted or in response to reports of species of interest (e.g., coastal aggregations of *Bp*). Several survey periods ranging from 4-14 days were scheduled annually with the goal of expanding seasonal data coverage and targeting periods of unrestricted range access as much as possible. The vessel was staffed with two observers, both experienced in all aspects of data collection for this project including vessel operation in close proximity to species of interest, photography, remote biopsy sampling, and satellite tag deployment.

Surveys at SCORE were based at Wilson Cove on the northeast side of SCI. The RHIB was deployed at either Dana Point or Oceanside Harbor at the start of a survey period and remained moored or hauled-out overnight in Wilson Cove throughout the scheduled survey period, or until poor weather or conflicting range operations prevented further surveys at SCORE. During typical operations, the RHIB would transit around the north end of the island each morning to the eastern boundary of SOAR. Staff from NUWC would monitor the hydrophones from the Range Operations Center on North Island in San Diego, and direct the RHIB via radio or satellite phone into areas where marine mammal vocalizations of interest were detected. While the RHIB could be directed toward any vocalizations for visual verification, it was preferentially directed to those likely to be beaked whales when conditions were suitable for working with these species (typically winds at Beaufort 3 or less). When conditions or scheduling precluded work with beaked whales, fin whales or other unusual acoustic detections requiring visual verification were targeted.

Each time a group of cetaceans was encountered, the species, time, latitude, longitude, group size and composition, and overall behavioral state were recorded. For encounters with beaked whales, detailed records of surfacing times and positions were also collected for as long as contact with the group was maintained. Photographs were taken for species verification where questionable, and for individual identification for species where this methodology was being employed either by this study or by those of collaborators. These species included beaked, fin, blue, humpback, and killer whales, and bottlenose and Risso's dolphins. Remote tissue biopsies were collected from species of interest both in this study (beaked and fin whales) and also for collaborators at the Southwest Fisheries Science Center (SWFSC) for ongoing assessments of offshore populations in the Bight (including Pacific white-sided, northern right whale, Risso's, and bottlenose dolphins, and killer whales). Finally, satellite tags were deployed predominantly on beaked whales, fin whales, Risso's dolphins, and killer whales. The tags deployed were of the Low Impact Minimally Percutaneous External-electronics Transmitter (LIMPET) design (Andrews *et al.* 2008, Schorr *et al.* 2009, 2014) in either the location-only SPOT5 or the SPLASH10 (initially called the MK10-A) configuration, which provided not only location, but also depth, data (Wildlife Computers, Inc., Redmond, WA).

Data Processing-- Photo Identification

At the completion of each survey, sighting data were compiled in a MS Access database. Photographs were reviewed, and those from *Zc* and *Bp* were processed to select the best identification photos of each individual within each group sighted as part of this grant. (Photographs of most other species were passed along to collaborators for further processing.) Annual sets of identification records were then sent to species-specific MS Access digital cataloging systems, where they were reconciled internally and compared to the existing catalog of individuals from previous years and other regions. Following each round of annual reconciliation, newly identified individuals were added to the photographic catalog, and all identification records were compiled into a multi-year, species-specific identification database that stored complete sighting histories and individual summary records of known whales for use in mark-recapture and other photo-ID analyses.

Starting in 2013, a new system was developed to improve matching efficiency for both *Bp* and *Zc*. Initially, these catalogs were organized, and catalog searches were structured, by subjective categorization of individuals based on the dorsal fin shape. These subjective categories were replaced with a standardized set of measurements, which were used to describe the shape of the fin as a set of proportions. After selection for matching within the digital catalog management system, the most complete and perpendicular image of the dorsal fin of each newly photographed individual was measured using the program ImageJ (Rasband 1997). A set of custom macros was developed to expedite this process so that these measurements could be collected consistently and accurately in approximately 2 minutes per image (Appendix I). These measurements were then uploaded into the digital catalog matching system, and used to rank returned whales in the catalog (both the current annual collection and the historical catalog) based on the similarity of their measurements to the whale being compared.

Following all photo reconciliation and catalog ID assignments, images of *Zc* were scored for a variety of factors related to their appearance. The complete set of photographs of each identified whale was systematically reviewed on a per-sighting basis to objectively describe its physical characteristics. The features scored for *Zc* included the presence or absence of erupted teeth, overall pigmentation pattern, apparent body size relative to other group members, extent of linear scarring, extent of ovoid scarring, and diatom coverage. These scores were then used iteratively and in combination with behavioral observations and genetic data (where available) to assign whales in the catalog to putative age and sex classes. A subset of confirmed adult females was first selected by association with a dependent calf, and then the scores of these whales were used to inform the range of pigmentation, scarring, and size associated with the adult female class. A subset of confirmed adult males was selected by the presence of erupted teeth in the lower jaw, and the composite scores for these individuals were used to inform the range of values seen in adult males. These criteria were used to sex large whales not associated with calves, but for which the presence or absence of teeth could not be confirmed. Remaining non-calves that fell below the pigmentation, scarring, and size criteria for adult males and females, were classified as sub-adults of unknown sex (unless they had been sexed genetically). Calves were determined by small size and persistent, close association with a presumed adult female over the course of a sighting.

Data Analysis-- Photo Identification

Mark-recapture calculations were conducted using the package RMark in the R computational environment, and also manually using the Chapman variant of the Lincoln-Peterson estimator for small sample sizes:

$$N \approx \frac{(K+1)(n+1)}{(k+1)} - 1,$$

where N = Number of animals in the population

K = Number of animals identified in the first sample

n = Number of animals identified in the second sample

k = Number of animals identified in both samples.

For *Zc*, all mark-recapture analyses used only medium to high quality photographs of the right side of adults. Images collected from small vessel surveys in 2006-2009 were added to those collected under this grant to improve sample size. These photographs were reconciled into annual captures for each individual to yield the largest, least biased sample possible, and sets of adjacent years were combined into pairs for use in the Chapman estimator to improve recapture data. Because previous data suggest the San Nicolas Basin (Figure 1) likely represents an area of high site fidelity (Falcone *et al.* 2009, Schorr *et al.* 2014), a closed mark recapture model was used to calculate an abundance estimate from data collected during surveys on SOAR only, where sampling was most consistent. For estimates calculated in RMark, the AIC value was used to assess model fit for different parameterizations of the same model type.

Age and sex class ratios were calculated for the entire *Zc* catalog, as well as for the set of unique individuals identified on each survey day, since the likelihood of missed matches is lower within each day than between days. The number of days sighted during the study was calculated for each whale in the catalog, and summarized for adults of each sex to assess differences in capture rates. Sighting histories of adult females sighted with at least one calf since 2006 were compiled and reviewed to summarize available data on weaning age and calving intervals.

While the identification data sample for *Bp* was larger than for *Zc*, recapture rates were relatively low and variable enough to limit the types of models that could be used to estimate abundance at this time, although not as severely limited as with *Zc*. Further, the geographic stratification of sampling effort (year-round opportunistic data were available inshore starting in 2009, while offshore sampling remained intermittent throughout that time) and inshore-offshore seasonal movement patterns (Douglas *et al.* 2014, and tag data presented here) make accurate mark-recapture estimation for *Bp* in this region more complex than for *Zc*, particularly with existing sample sizes. We calculated abundance estimates using the complete annual photographic datasets (dedicated and opportunistic sources) from 2009-2012, first combined for inshore and offshore data, and then for the inshore sample only. (Offshore only samples would contain too few recaptures for models to run successfully.) Data were analyzed using simple closed models, first manually calculated and then parameterized in RMark as described for *Zc*, and also using the POPAN open population model in RMark. POPAN was used to estimate the abundance of an open super-population, along with apparent survival rates (which would include effects of both mortality and permanent emigration), probability of entry into the population at a given time (including effects of both birth and immigration), and the capture probability. As with *Zc*, AIC values were used to assess fit among similar model types, where appropriate.

Data Processing and Analysis-- Satellite Telemetry

A. Movement Data

Telemetry data collected in previous years of this project (2008-2009) were included in movement analyses reported here. We used the Douglas Argos Filter to remove implausible Argos location estimates (Douglas *et al.* 2012). User-defined filter parameters for each species are outlined in Table 1. The program Mysticetus (Version 1.9.0.197, Entiat River Technologies, Preston, WA) was used to determine the depth, distance to shore (closest land), and presence within designated Navy ranges and distinct geographic regions for all filtered locations. The best daily locations, as determined by the Douglas Argos Filter, were used to generate distance to deployment figures and to calculate daily rates of horizontal movement for locations received between 12 and 36 hours apart. These rates were used to assess seasonal rates of sustained movement.

To assess seasonal trends in distribution for *Bp* in the SCB, we selected a subset of locations between 32.2^{o}N and 34.6^{o}N latitude, which encompasses most designated training areas within SOCAL. For each location, we assigned it to the season during which it was collected (summer, fall, winter, spring), and calculated the distance to the mainland coast. Seasonal distribution maps were generated from the resulting dataset, and a Bonferroni Multiple Comparison test was run to assess seasonal differences in the distance to the mainland coast.

Table 1. User-defined settings in the Douglas Filter (Douglas *et al.* 2012), by species.

Species	Min-rate	Max-redun	Rate-coef	KeepLC
Zc	10	3	25	2
Bp	20	3	25	2

B. Dive Data-- Cuvier's Beaked Whale

Behavior Log data from *Zc* were collected and processed as described in Schorr *et al.* (2014). Briefly, dives were defined as any submergence that exceeded 50 m depth and lasted longer than 30 s, and each dive record provided the start time, end time, maximum depth reached, and dive shape. A K-means cluster analysis was then used to partition all dives into 'deep' (presumably foraging) or 'shallow' (presumably non-foraging) dive classes, based on their depth and duration. Surfacings represented the time between qualifying dives (i.e., when the whale did not descend below 50 m for more than 30 s), and included the start/end times only. The Inter-Deep Dive Interval (IDDI) was calculated as the time between the end of one deep dive and the start of the next (Tyack *et al.* 2006).

To summarize *Zc* behavior in the absence of MFAS exposure, we identified periods where no sonar was reported for a series of consecutive days when tags were active near SOAR. In collaboration with the NUWC M3R group (Moretti, Watwood, McCarthy) and the Navy, we obtained sonar use records from the Sonar Positional ReporTing System (SPORTS) database for periods when tags were active. Descriptive statistics were calculated as in Schorr *et al.* (2014) for active tags during extended sonar-free periods, and the results compared between the two datasets.

C. Dive Data -- Fin Whale

Descriptive statistics were calculated for nine fin whales tagged with behavior logging tags. The start and end of each dive were defined as the time when the animal first descended or ascended through 5 m depth during any submergence deeper than 20 m and lasting longer than 30 seconds. The percentage of time spent above 20 m was calculated by summing all time at the 'surface' between qualifying dives and dividing it by the total duration of the diving behavior record.

Results and Discussion

Survey Effort and Sighting Rates

Survey effort and data collection from June 2010 - January 2014 are summarized in Table 2. Throughout this period, surveys were conducted during 8 different months, though effort was disproportionately focused in winter and spring months to balance previous efforts in the region which had occurred predominantly in the late summer and fall.

Table 2. Summary of effort by survey year. An 'Identification' was counted as each time an individual group member was photographed for identification purposes in the field. *Bp* identifications from 2013 and 2014 were not finalized at the time of this report, and thus numbers reported are preliminary estimates.

Year	Survey Days	Effort Hrs	Sightings	Biopsies	Tags Deployed	*Zc* Identifications	*Bp* Identifications
2010	17	139.2	94	11	7	12	10
2011	23	198.9	125	12	11	22	16
2012	20	158.9	106	13	20	12	54
2013	23	192.4	137	11	21	27	~72
2014	8	62.8	31	0	7	18	~15

By combining all cetacean sighting records from surveys conducted around SCORE during both this study period and prior efforts in 2006-2009, which included effort in an additional month, some seasonal trends in cetacean occurrence are apparent despite the non-systematic nature of these surveys (Table 3). The majority of SCORE-based surveys focused on the deep waters of the San Nicolas Basin, with a lesser focus on the shallower, nearshore waters adjacent to the island, and this influenced sighting rates of several species with habitat-related distributions. Eighteen total cetacean species were encountered (including both long-beaked and short-beaked common dolphins, combined as a single line in Table 3, and two ecotypes of killer whale, which were separated), though encounter rates with most species were low.

Among the larger whales, only fin whales were encountered routinely around SCORE in every month surveyed, with a peak in observation rate during March and July. Encounters with minke and humpback whales occurred sporadically in most months, suggesting these species may be present year-round in low numbers. Gray whales were noted in the near-shore waters along both the east and west sides of SCI and to a lesser extent in the deep waters of the San Nicolas Basin in January during their southbound migration. Because of frequent restrictions on near-shore navigation and an effort bias toward deepwater habitat, gray whale encounter rates are under-represented in this dataset; however, whales were frequently visible from shore during January surveys. Sumich & Show (2011) described from aerial surveys in 1988-1990 the importance of offshore migratory corridors along SCI for southbound gray whales, and our observations suggest that pattern has continued in the decades since. Encounters with northbound gray whales in March-May were rare. Small numbers of blue whales also occur around SCORE, with sightings almost exclusively in summer and early fall. A single adult male sperm whale was sighted in July 2011.

<u>Table 3.</u> The average number of individuals sighted per day of effort, by species and month, during surveys based at SCORE from 2006-2014. The total number of months each species was sighted is on the right, the total number of species sighted per month at bottom.

	Month	**Jan**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Oct**	**Nov**	
	Years Surveyed	**4**	**2**	**1**	**1**	**1**	**2**	**2**	**3**	**3**	**Months**
	Vessel Days	**19**	**14**	**10**	**5**	**10**	**18**	**47**	**44**	**10**	**Seen**
Large Whales	***Ba*, Minke Whale**	0.1	0.1		0.2	0.1	0.2	0.1	0.1		**7**
	***Be* , Bryde's Whale**						0.1	0.1			**2**
	***Bm*, Blue Whale**			0.1		0.1	0.1	0.2	0.0		**5**
	***Bp*, Fin Whale**	2.9	6.3	0.5	3.0	2.3	6.0	1.9	3.3	0.8	**9**
	***Er*, Gray Whale**	2.5	0.6								**2**
	***Mn*, Humpback Whale**	0.1	0.4	0.7			0.1		0.2	0.3	**6**
	***Pm*, Sperm Whale**						0.1				**1**
Delphinids and Porpoises	***Dsp*, Common Dolphin**	165	89	89	9	150	338	243	109	210	**9**
	***Gg*, Risso's Dolphin**	8.3	21.5		10.2	11.9	15.4	11.8	0.1	4.6	**8**
	***Gm*, Short-finned Pilot Whale**								3.4		**1**
	***Lb*, Northern Right Whale Dolphin**	3.8	104.1	1.6	99.0	1.0	1.4		3.9		**7**
	***Lo*, Pacific Whitesided Dolphin**	7.6		12.9		6.5	13.7	1.0	0.7		**6**
	***OoOff*, Killer Whale-Offshore Ecotype**	0.6									**1**
	***OoTr*, Killer Whale-Transient Ecotype**	0.6	1.0								**2**
	***Pd*, Dall's Porpoise**	4.2	1.1		0.4				0.3	1.2	**5**
	***Tt*, Bottlenose Dolphin**	2.3	1.2	10.0	5.4	9.0	14.4	18.2	1.0		**8**
Beaked Whales	***Bba*, Baird's Beaked Whale**			0.2							**1**
	***Zc*, Cuvier's Beaked Whale**	2.9	1.3		2.0	1.2	1.1	1.1	1.9	1.0	**8**
	Total Monthly Species	**13**	**11**	**8**	**8**	**9**	**12**	**9**	**12**	**6**	

Common dolphins are present in large numbers year round, and it should be noted that numbers from this study are biased low because this species was often actively avoided during M3R surveys, when their vocalizations compromised the ability to detect species of interest. Risso's and bottlenose dolphins are also present in moderate numbers at SCORE year-round. As with gray whales, the number of bottlenose dolphins sighted was biased low since they were most often sighted close to the island, where survey effort was lowest. Northern right whale dolphins, Dall's porpoises, and pacific white-sided dolphins were all encountered predominantly in colder months, and northern right whale dolphins in particular occurred regularly in large groups in winter and spring, often associated with other cetacean species.

Cuvier's beaked whales were encountered in the deep waters of SOAR during all survey months but April (when weather was predominantly poor). *Zc* were sighted on average once every 20.8 hours of survey effort from 2010-2014, including effort in all survey conditions and areas regardless of habitat suitability. When effort was restricted to within the boundaries of SOAR, the rate was one *Zc* encounter for every 10.8 hours of effort. And if this sample were further restricted to hours on SOAR in "excellent" or "good" survey conditions (generally winds Beaufort three or less with no significant visual impairment due to atmospheric conditions or swell height), *Zc* were sighted on average once every 6.7 hours of survey effort. The M3R system greatly improves the ability to find and work with this and any other beaked whale species on the instrumented range (Moretti *et al.* 2006, 2014), though the only other species that has been encountered there to date is Baird's beaked whale, with one encounter during earlier M3R surveys in 2007, and one each in 2010 and 2012 during effort associated with the SOCAL BRS study (Southall *et al.* 2014).

Much of the cetacean seasonality we observed has been described or suggested from infrequent large-scale, systematic visual survey data or long-term passive acoustic monitoring, which are methods better suited to this type of comparison (Forney & Barlow 1998, Douglas *et al.* 2014). However, these studies have included minimal effort in the waters immediately adjacent to SCI or within SOAR. Also, these surveys are unable to characterize the populations of species with low or sporadic sighting rates or fine-scale geographic variation, most notably the beaked whales, which appear to occur in much higher densities in the San Nicolas Basin than larger scale studies have detected (Falcone *et al.* 2009). Given the levels of anthropogenic activity in this area of diverse habitat, and thus diverse cetacean abundance, finer scale data collection should be continued to detect any possible changes related to local training activities.

Photo-Identification-- Cuvier's Beaked Whales

From the estimated 174 *Zc* that were approached during small-vessel surveys at SCORE since such effort began there in 2006, 145 were successfully photographed for identification purposes. These identifications represented sightings of 104 unique individuals, which were sighted on up to 4 different days and in as many as 4 different years, suggesting at least some whales exhibit residency to the San Nicolas Basin. There have been relatively few published longitudinal photo-ID studies of beaked whales; however, most have suggested the focal species formed localized populations with limited ranges and apparently low rates of dispersion (Gowans *et al.* 2000, McSweeney *et al.* 2007, Claridge 2013), and this appears to also be true of *Zc* off Southern California.

A sample of 118 annual captures of 94 unique adults with medium-high quality photos of the right side of the body was used to estimate abundance. A closed mark-recapture model with capture/recapture probability held equal and constant across annual samples provided the best fit for this small dataset. The capture/recapture probability was estimated at 0.062 and the abundance was estimated at 235 adults in the population. This abundance estimate agrees well with numbers derived from comparing among sets of combined annual samples using the Chapman variant of the Lincoln-Petersen estimator (Table 4), though ultimately neither may be the most appropriate analytical method for assessing abundance in this population. At least one longer term mark-recapture study has successfully used more complex Bayesian statistical methods to estimate abundance, capture and recapture probabilities, and apparent survival rates (which account for emigration/immigration) in another beaked whale species (*Mesoplodon densirotris, Md*) while accounting for heterogeneity in these parameters related to age and sex class (Claridge 2013), despite limited annual sample sizes. While this method estimated these parameters with improved confidence, overall estimates of abundance were similar between models that did and did not account for heterogeneity. Thus, we feel that an abundance estimate in the low hundreds of adult *Zc* is likely reasonable for the San Nicolas Basin. With continued data collection in coming years, more complex analytical methods that can account for heterogeneity should provide improved estimates and a more complete understanding of demographic effects in this population than the preliminary methods used here, as it is likely that age- and sex-related heterogeneity also occur with *Zc*. Further, tag data (see below) have shown that some individuals do emigrate, at least temporarily, from the San Nicolas Basin, which needs to be accounted for in future analyses as our sample improves. Our current sample, in order to maintain an adequate sample size, was also not restricted by individual distinctiveness. As has been noted previously (Falcone *et al.* 2009), the mark rates of calves, sub-adults, and even some adult females are lower in this population than they are in other studied beaked whale populations whose range overlaps more with cookie cutter sharks, the bites of which provide an additional source of persistent scarring across all age and sex classes (McSweeney *et al.* 2007, Claridge 2013). While all adult males in our sample were consistently well-marked, some adult females and most calves and sub-adults were minimally marked, and this may reduce the odds of successful recapture for whales in these classes, even with high quality photographs. Though we attempted to mitigate for this by limiting our sample to higher quality images of adults only, the inclusion of some minimally marked adult females may have increased the odds of treating a re-sighted whale as a new individual, which would positively bias the abundance estimate.

Table 4. Abundance estimates for adult *Zc* in the San Nicolas Basin, using the Chapman variant of the Lincoln-Petersen estimator to compare recapture rates among sets of year pairs.

Sample 1	Sample 2	n ID1	n ID2	n ID12	N	CV	CI 95%-L	CI 95%-U
2007-2008	2009-2010	36	17	2	332	0.29	229	481
2007-2008	2011-2012	36	21	8	101	0.15	83	122
2007-2008	2013-2014	36	26	3	332	0.27	236	466
2009-2010	2011-2012	17	21	2	197	0.28	137	282
2009-2010	2013-2014	17	26	3	161	0.25	117	221
2011-2012	2013-2014	21	26	3	197	0.26	142	273
	Average Population Estimate Across Years				**220**			

An increased likelihood of missed matches among less distinctive adult females may also contribute to a female-biased sex ratio among adults in this study, though several real biological processes may also contribute to this pattern. Again using small-vessel survey photos collected at SOAR from 2006-2014, there were 51 individual adult females (49%), 25 adult males (24%), 14 sub-adults (13%), 7 calves (7%), and 7 individuals of unknown age/sex (7%) identified in the course of this work. When this same dataset was parsed into daily sex ratios to control for missed matches between days (which are most likely among females and sub-adults), the sex ratios remained highly skewed toward adult females (Table 5). This suggests that failed matches between days for adult females are less likely to be a major factor in the sex distribution of the overall catalog, though failed matches involving calves and sub-adults may well be occurring (and hence their exclusion from mark-recapture models). The distribution of days sighted per individual was similar for adult males and females (Figure 2). It does not appear that individual males tend to be sighted less often than individual females, which might be expected if males tend to have lower site fidelity to the basin or larger home ranges that only partially include it. They do appear to be re-sighted at slightly higher rates than adult females, which might be expected if their distinctiveness artificially increased their recapture probability over less-marked females. It was also noteworthy that four whales were classified as adult females based on body size (large relative to other group members), pigmentation (extensive pale coloration beyond the blowhole), and confirmed lack of erupted teeth, but which had unusually heavy linear scarring relative to adult females whose age and sex were confirmed by association with a calf. While most adult males of similar size and pigmentation (but with erupted teeth) were more heavily and deeply scarred than these presumed adult females, it can't be ruled out that these are actually males without erupted teeth. If so, this would artificially increase the number of females in the catalog. We are unaware of any reports of this occurring in beaked whales, though such data are limited. To date, none of these four heavily scarred females has been seen with a calf, also raising the possibility that they are older, potentially post-reproductive females who have simply had more years to acquire scars-- though with only one sighting each, this is purely speculative. A long post-reproductive life span for females would also contribute to a female-bias in the population, as is seen in resident killer whales (Olesiuk *et al.* 1990).

Table 5. Average daily sex ratios by year among individual *Zc* identified during surveys based at SCORE.

Year	Days	Adult-F	Adult-M	Sub-Adult	Calf	Unk
2006	1	1.00	0.00	0.00	0.00	0.00
2007	4	0.34	0.48	0.09	0.00	0.09
2008	4	0.58	0.11	0.08	0.13	0.10
2009	2	0.63	0.13	0.25	0.00	0.00
2010	2	0.56	0.44	0.00	0.00	0.00
2011	5	0.44	0.31	0.14	0.12	0.00
2012	3	0.37	0.57	0.07	0.00	0.00
2013	6	0.58	0.13	0.21	0.08	0.00
2014	4	0.54	0.17	0.21	0.04	0.04
Overall Daily Averages		**0.56**	**0.26**	**0.12**	**0.04**	**0.03**

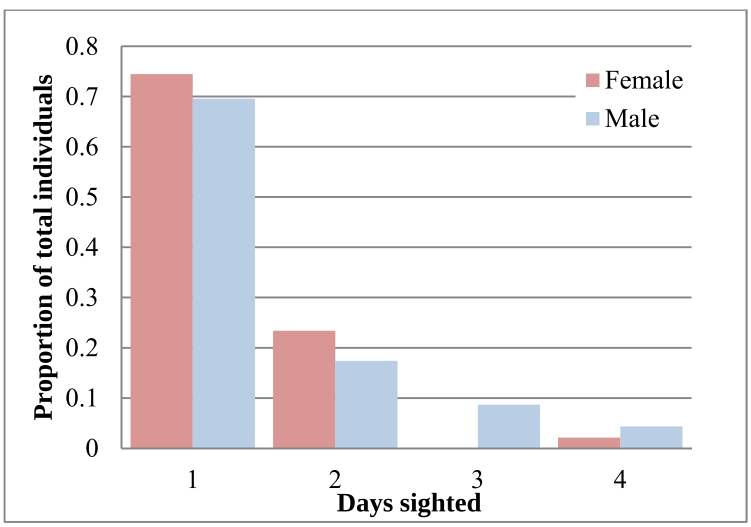


Figure 2. Total days sighted for adult male and adult female *Zc* identified at SCORE from 2006-2014.

In two other studies of beaked whales (*Zc* and *Md* in Hawaii, McSweeney *et al.* 2007; and *Md* in the Bahamas, Claridge 2013), the reconciled catalogs were also female-biased, though not as heavily. For

Md in the Bahamas, female bias was partially explained by the fact that adult males are the class most likely to be found solitary, and solitary individuals are less likely to be sighted than whales in larger groups. Further, groups containing multiple individuals in both the Bahamas and Hawaii seldom contain more than one adult male, further reducing the overall capture rate of males in those studies. Adult males also predominated among solitary individuals in our dataset, accounting for 55% of single-whale sightings (n = 11), followed by adult females (27% of solitary individuals), and 18% solitary individuals of unknown age and sex (likely to be older sub-adults). In contrast to these other studies, however, groups containing more than one adult male were not uncommon in this dataset, with 13 (40%) of 37 groups of multiple animals including 2-3 adult males, though these groups tended to be larger than average (mean group size = 6.5 whales for groups with >1 male vs. 4.4 whales for all groups >1). Given the consistently skewed sex ratio in these data and the evidence of intra-specific competition among males in *Zc* (erupted teeth and associated heavy scarring on adult males) (Heyning 1984), it is likely that this species is also engaging in female defense polygyny, though perhaps not as strongly as *Md*. In contrast, studies of the larger northern bottlenose whale (*Hyperoodon ampullatus*) have revealed stable associations among adult males (Gowans *et al.* 2001). Our findings suggest *Zc* in Southern California may have a social system intermediate to these two species, with elements of both, though our data are insufficient to assess the stability of associations between the males sighted together in multi-male groups. The sex ratio skew and recapture rates of males in our study may suggest that the turnover rate among dominant adult males in this area is low, and that sub-adult males may be more likely to disperse than females.

Ten of the 51 adult females identified in the course of this work were sighted with at least one calf between 2006 and 2014. Six of these females were sighted on more than one occasion, and one of these females, CRC103, was sighted with two calves across four consecutive years of sightings. These data provide the first insights into female reproductive cycles in this population (Table 6). CRC103 was first sighted on 02 May 2011 with a calf in attendance. She was then sighted on 15 January 2012 and again on 29 March 2013, without a calf in either group. On 06 January 2014, approximately 9 months after her previous sighting, she was sighted with her second calf, indicating a calving interval of 3-4 years for this whale. It also suggests this female rested a year between weaning her first calf and becoming pregnant again. There were three cases where a female was sighted with a calf and then subsequently sighted without a calf. The intervals between these sightings were 0.7, 1.9, and 2.2 years. There were two cases where a female was seen without a calf in one sighting and with a calf in the next; these sighting intervals were 0.8 and 1 year. There were three females sighted with calves on two subsequent occasions, these were 1 day, 0.2, and 0.4 years apart. These intervals suggest that calves are likely weaned at 1-2 years of age, though it should be noted that due to the low mark rates of calves and sub-adults in this population, from photos alone recaptures can seldom be made between these two classes and it will be difficult to confirm whether a sub-adult sighted in the same group as a known adult female could be her previously sighted calf.

Table 6. Sighting histories of six adult female *Zc* that were sighted with and without calves between 2006 and 2014. The asterisk denotes a sighting in which both these females were present with an older calf not very closely associated with either female. The calf was believed to belong to CRC127, though this could not be confirmed by photos due to lack of markings.

Female ID	Sighting Date	With Calf?	Years Since Previous Sighting
23	24-Oct-07	No	--
23	24-Oct-08	Yes	1.0
23	29-Sep-10	No	1.9
50	22-Oct-08	Yes	--
50	23-Oct-08	Yes	0.0
54	23-Oct-08	Yes	--
54	05-Jan-11	No	2.2
103	02-May-11	Yes	--
103	15-Jan-12	No	0.7
103	29-Mar-13	No?*	1.2
103	06-Jan-14	Yes	0.8
126	05-Jan-13	Yes	--
126	20-May-13	Yes	0.4
127	05-Jan-13	Yes	--
127	29-Mar-13	Yes?*	0.2

Moore & Barlow (2013) used line-transect survey data to detect a declining trend in *Zc* abundance in the California Current ecosystem from 1991-2008, though the cause of the decline was not clear. The San Nicolas Basin represents a very small portion at the southern end of that study area, but photo-ID is providing the first opportunity to understand finer scale population dynamics for *Zc* within this larger area of concern, and *Zc* photo-ID effort in this region should be continued into the future. Ideally, another photo-ID study should be initiated for a reference *Zc* population elsewhere in the California Current ecosystem to assess the degree to which impacts associated with military training exercises might differentially affect whales in the San Nicolas Basin. Passive acoustic studies have suggested that *Zc* are the predominant beaked whale species in the Monterey Canyon (Baumann-Pickering *et al.* 2014), a region to the north that is readily accessible by boat from the mainland coast. A comparison of population dynamics and vital rates between these areas could be informative.

Photo-Identification-- Fin Whales

Photo-identification of *Bp* in the Southern California Bight has occurred within a larger effort to understand the population structure of fin whales along the coast of western North America (Table 7). From 1992-2012, 338 individuals have been identified between Point Conception and the US-Mexico border, at distances up to 356 km from the mainland coast. Prior to 2009, *Bp* photos were predominantly collected opportunistically during sporadic surveys in the outer waters of the Southern California Bight (from 30-100 km from the mainland coast), and almost exclusively in summer and early fall. Beginning in 2009, *Bp* sightings in the nearshore waters of the Bight (<30 km from the mainland coast) increased considerably, particularly during late fall and winter months which were previously underrepresented. This trend has persisted, and through occasional nearshore surveys associated with this project and opportunistic photo contributions from naturalists, tour operators, and other coastal surveys by CRC staff and collaborators, the geographic and temporal distributions of *Bp* identifications have shifted in recent study years, and individual re-sightings both within and between study years have increased.

Table 7. Summary of *Bp* photo-identification along the west coast of North America, including photos collected as part of this study, other research by CRC and collaborating organizations (SWFSC, Dept. of Fisheries and Oceans Canada, Aquarium of the Pacific), naturalists, and tour operators.

Region	First Year	Last Year	Identification Records	Identifications with ID	Unique IDs	Avg Identifications per ID
British Columbia-Southeast Alaska	2004	2009	110	92	48	1.92
Oregon-Washington	2005	2012	67	63	55	1.15
Northern California	1987	2012	96	65	54	1.20
Southern California Bight	**1992**	**2012**	**1090**	**692**	**338**	**2.05**
Mexico-Eastern Tropical Pacific	2003	2011	41	29	21	1.38

Individual *Bp* off Southern California were identified on an average of 2 days each in the study period, though the majority of whales were only seen once. As was reported previously (Falcone *et al.* 2011), *Bp* identified off Southern California were rarely identified elsewhere, suggesting extra-regional movements are relatively infrequent, though sampling outside Southern California is much more limited and seasonally biased. A subset of 95 whales were seen on as many as 21 different days off Southern California, and 49 of these whales were sighted in up to 5 different years. Whales with the highest numbers of daily sightings were found predominantly in nearshore waters, which in part reflects heavy sampling in later study years when coastal *Bp* sightings increased. Because sampling in the outer waters did not occur as consistently as inshore sampling, it was difficult to characterize the relationship between the whales using the inner and outer waters of the Bight. To date, 21 (22%) of 95 whales identified more than once off Southern California have been sighted both within and beyond 30 km of the mainland coast. It is notable that 49 re-sighted whales were seen in multiple seasons (to a maximum of all four), which suggests that at least some individual whales are present in the region year-round, and that the low inshore-offshore recapture rate may result from under-sampling offshore regions in the summer relative to inshore regions in the winter. This, combined with the limited movements of satellite tagged individuals (see below), suggests that there may be a sub-population of *Bp* that ranges broadly throughout the Southern California Bight year-round, aggregating coastally in fall and winter and dispersing throughout the outer waters in summer and spring. Non-migratory populations of *Bp* have been described elsewhere, so this pattern may not be uncommon within the species. However, these populations tend to occur in more geographically isolated seas, such as the Gulf of California and the Mediterranean Sea (Tershy *et al.* 1993, Bérubé *et al.* 2002), so the presence of a distinct population within the continuous waters that *Bp* use along the west coast seems more unusual. Genetic data has also suggested a population boundary may exist for fin whales in Southern California (Archer *et al.* 2013).

After restricting the data to right sides of non-calves and to medium to high quality images, the sample used to estimate abundance for *Bp* included 173 annual captures of 141 individuals photographed in Southern California from 2009-2012. Using the Chapman variant of the Lincoln-Peterson estimator to compare among pairs of sample years resulted in an average abundance estimate of 298 whales (range 167 - 556, n = 6 year pairs, Table 8A). Further restricting the sample to identifications collected inshore resulted in an average estimate of only 164 whales (range 106 - 264, Table 8B). A comparison among simple closed models using RMark suggested one, in which capture and recapture probability were equal but varied annually, fit the data best (AIC = -542.3). This model produced capture probabilities ranging from 0.08 in 2011 to 0.18 in 2012 and an estimated abundance of 312 individuals. This was followed by the model in which capture and recapture probabilities were equal and constant at 0.14 (AIC = -535.3), with an estimated abundance of 318 whales. These two models agreed well with the Chapman estimator results for paired years. The final model, with capture and recapture probabilities constant but different at 0.07 and 0.14 respectively (AIC = -534.3) resulted in an abundance estimate of 570 individuals.

Table 8. Population estimates for Southern California *Bp*, using photos collected from 2009-2012 in both inshore and offshore regions (**A**), and in inshore regions only (**B**).

A.

Year 1	Year 2	n ID1	n ID2	n ID12	N	CV	CI 95%-L	CI 95%-U
2009	2010	42	47	8	257	0.18	204	323
2009	2011	42	27	4	300	0.24	221	408
2009	2012	42	57	9	276	0.17	222	343
2010	2011	47	27	8	167	0.17	135	207
2010	2012	47	57	5	556	0.23	413	749
2011	2012	27	57	7	231	0.18	182	293
Average Population Estimate Across Years					**298**			

B.

Year 1	Year 2	n ID1	n ID2	n ID12	N	CV	CI 95%-L	CI 95%-U
2009	2010	35	38	7	200	0.18	158	253
2009	2011	35	21	5	157	0.21	121	205
2009	2012	35	33	9	135	0.15	111	164
2010	2011	38	21	8	106	0.15	87	129
2010	2012	38	33	5	264	0.22	199	350
2011	2012	21	33	6	124	0.18	98	156
Average Population Estimate Across Years					**164**			

Using the same combined inshore-offshore dataset in the POPAN open population model resulted in similar abundance estimates to both closed models. The data were best fit by a model in which apparent survival and capture probability were constant at 0.74 and 0.24, respectively, but in which the probability of entry into the population varied annually from nearly zero to 0.35 (AIC value 216.55). This resulted in an abundance estimate of 352 whales. The next best fit model ranked only slightly below (AIC 216.58), and assumed time-varying capture probability while all other parameters were held constant. In this case, apparent survival was 0.78, probability of entry was 0.17, and capture probability ranged from 0.14 - 0.28. This produced an abundance estimate of 326 whales. The third model run assumed both apparent survival and probability of entry varied annually, but capture probability did not (AIC 216.84). Apparent survival estimates ranged from 0.54 to nearly 1, probability of entry ranged from 0.02 to 0.36, capture probability was constant at 0.22, and the abundance was estimated at 355 whales. These abundance estimates agree well with those from the closed models, though the additional parameters modeled here suggest that there may be a fairly stable core population of approximately 100-200 whales, which increasingly use the inshore waters, with a smaller proportion of animals that are passing in and out of the region each year and which predominantly use the under-sampled outer waters. This could explain the lower apparent survival rates and high probabilities of entry estimated by the POPAN model. Continued data collection and more complex analytical techniques should help resolve the structure and stability of the fin whale population off Southern California.

Fin whales off Southern California are currently managed as part of a California-Oregon-Washington population estimated at approximately 3000 individuals (Carretta *et al.* 2012). If this population definition is accurate, our numbers suggest that roughly 10% of this population may be using the Southern California Bight preferentially, with a smaller percentage of these whales increasingly using the busy inshore waters. Using line-transect survey data from 1991-2005, Barlow & Forney (2007) estimated the abundance of *Bp* in Southern California at 359 (CV = 0.4), which agrees well with the mark-recapture results and suggests that *Bp* abundance may have remained fairly stable in the ensuing years, though the CV associated with the earlier estimate indicates a considerable degree of uncertainty. Moore & Barlow (2011) provided evidence that fin whale abundance was increasing in the California Current from 1991 - 2008, and, barring changes in population dynamics, continued growth was expected. However, they also noted that the trend was less consistent in the southern portion of their study area. It is notable that both our photo-ID data and other genetic analyses (Archer *et al.* 2013) suggest there could be differentiation in the fin whale population north and south of Point Conception, and thus the population increases in Moore & Barlow (2011) may not be occurring uniformly along the US West Coast, because that study included two distinct population segments.

Ship strike has been cited as a risk to fin whales in this region, and this risk may be disproportionately high for whales that tend to aggregate along the densely populated coast around Los Angeles-Long Beach in fall and winter, and also on the SOAR range in spring and summer. Redfern *et al.* (2013) suggested the ship strike risk to fin whales in Southern California is likely below the potential biological removal rate set by the National Marine Fisheries Service. However, this estimate did not account for the fact that fin whale carcasses are much less likely to be recovered if they are struck in their offshore habitat (relative to the carcasses of more coastally distributed blue whales, for which there is currently greater concern), or that fin whales off Southern California may not be from the same large and growing population from which takes are currently estimated. It also predominantly relied on data from prior to the apparent inshore winter distribution shift that started in 2009, and thus may have underestimated their use of the most heavily trafficked areas in the region.

It is also interesting that although there are indications of a year-round sub-population of fin whales off Southern California, with increased sighting rates in coastal waters during winter, young calves are nevertheless seldom sighted. In fact, young fin whale calves have rarely been documented in either historic whaling records (Clapham *et al.* 1997, Mizroch *et al.* 2009) or in more recent sighting data from the eastern North Pacific used in this larger photo-ID study. Whaling data have shown that fin whales, like other large baleen whales, appear to give birth primarily in winter; however, they do not display clear seasonal migratory patterns associated with their reproductive cycle in the North Pacific, as they do in other oceans (Mizroch *et al.* 2009). To date, we have sighted only one neonate calf during this study, in November on the SOAR range. The calf was very small and potentially pre-term. We have noted increased surface-oriented social behavior and larger group sizes among fin whales sighted in surveys from November through March, including "racing" behavior associated with courtship in blue whales, and thus it is likely whales are engaging in reproductive behavior during winter. However, this does not appear to include routine use of the area for calving. At a minimum, this suggests there may be heterogeneity in capture rates related to age, sex, and reproductive status in this population that might affect abundance estimates. Because fin whales are not sexually dimorphic, and even older calves are infrequently sighted (thus providing a sex for the mother), the only reliable way to sex a sizeable number of individuals in this population and integrate this covariate into future population models will be through increased genetic sampling of individuals that are photographed. This should be considered for future efforts to improve our understanding of age and sex stratified demography, distribution, and impacts.

Satellite Telemetry-- Cuvier's Beaked Whales

Eighteen beaked whales were tagged between 2008 and January 2014. In this report, we summarize the movements and habitat use of all 18 whales. As the diving behavior from eight of these tags was described in previous contract reports and published recently in Schorr *et al.* (2014), in this report we only summarize dive data from a subset of tags that were active on or near SOAR during two periods when MFAS was not reported within the SCB-- providing our first sizeable sample of behavior in the absence of this type of disturbance.

Movements and Habitat Use-- Cuvier's Beaked Whales

The two earliest tags deployed on *Zc* were location-only Argos transmitters (Spot5, Wildlife Computers, Redmond, WA); all others provided both location and diving behavior data (SPLASH10, Wildlife Computers, Redmond, WA). The majority of whales (n = 16) were tagged on the SOAR range; however two tags were deployed in the Catalina Basin, off the NE corner of San Clemente Island, in 2014. The median transmission duration for all tags was 44.8 days (range = 7.2 – 121.3, n = 18), providing 2581 locations (Table 9). Grand mean distance to deployment for these locations was just 38 km (sd = 46.1), though the maximum distance traveled from tagging location was 697 km (Figure 3).

Early photo-ID and telemetry data have suggested that animals tagged on the SOAR range exhibit a high degree of site fidelity to the San Nicolas basin (Falcone *et al.* 2009, Schorr *et al.* 2014). Six of the tagged whales have been photographed in more than one year, with the time between re-sightings ranging from 0.5-5.4 years (Table 10). Movements beyond the basin have continued to occur primarily into the Santa Cruz Basin to the north or Tanner Canyon to the south, though several whales have made larger extra-regional movements, mostly to the south. Movements into the Catalina Basin, which lies immediately east of the San Nicolas Basin, have been strikingly uncommon despite close proximity and the fact that *Zc* are known to occur there (Yack *et al.* 2013). In total, we have 688 days of tracking data from 16 *Zc* tagged on SOAR. Only two of these whales entered the Catalina Basin during their transmission period: one individual was present on one day, another for two days, representing less than 2% of their total transmission durations (Table 11). The first two tag deployments on whales in the Catalina Basin also revealed limited movement patterns. While these two whales were in the same group when tagged, they separated within 1 day. In a total of 103 days of independent movement data from these two whales, only two poor quality locations were received from within the San Nicolas basin, both of which were right along the boundary of the Catalina Basin and associated with a degree of uncertainty. This suggests some *Zc* in the SCB may exhibit a degree of basin-specific site fidelity (Figure 4), despite a demonstrated ability to move extensive distances. Even within the San Nicolas Basin, most whales preferentially used the central and western sides of the basin, suggesting core use areas within a preferred basin may be quite small (Figure 4).

Table 9. Deployment summaries for 18 *Zc* tags. Spot5 tags provided location data only; SPLASH10 tags provided locations and diving behavior.

TagID	Date Deployed	Transmission Duration (Days)	Num. Locations	Median Dist to Deployment location (Range)	Location Tagged	Tag Type
ZcTag004	8/3/2008	121.3	350	41 (2-152)	SOAR	Spot5
ZcTag007	7/20/2009	42.4	179	12 (1-697)	SOAR	Spot5
ZcTag010	6/29/2010	53.6	172	68 (5-266)	SOAR	SPLASH10
ZcTag011	6/29/2010	89.8	175	199 (4-289)	SOAR	SPLASH10
ZcTag014	1/6/2011	22.5	81	18 (2-94)	SOAR	SPLASH10
ZcTag015	1/6/2011	70.6	292	84 (4-452)	SOAR	SPLASH10
ZcTag016	1/6/2011	88.7	195	20 (1-103)	SOAR	SPLASH10
ZcTag017	7/23/2011	9.7	43	29 (6-236)	SOAR	SPLASH10
ZcTag019	1/15/2012	12.0	50	12 (1-33)	SOAR	SPLASH10
ZcTag020	1/15/2012	26.4	122	17 (1-42)	SOAR	SPLASH10
ZcTag021	3/29/2013	47.3	132	72 (0-122)	SOAR	SPLASH10
ZcTag022	3/30/2013	27.8	65	11 (1-41)	SOAR	SPLASH10
ZcTag023	3/30/2013	7.2	24	14 (2-37)	SOAR	SPLASH10
ZcTag024	1/4/2014	11.8	41	17 (0-61)	SOAR	SPLASH10
ZcTag025	1/4/2014	8.2	33	21 (2-56)	SOAR	SPLASH10
ZcTag026	1/7/2014	47.2	194	24 (2-46)	Catalina	SPLASH10
ZcTag027	1/7/2014	57.8	255	17 (1-47)	Catalina	SPLASH10
ZcTag028	1/11/2014	48.6	178	10 (0-27)	SOAR	SPLASH10

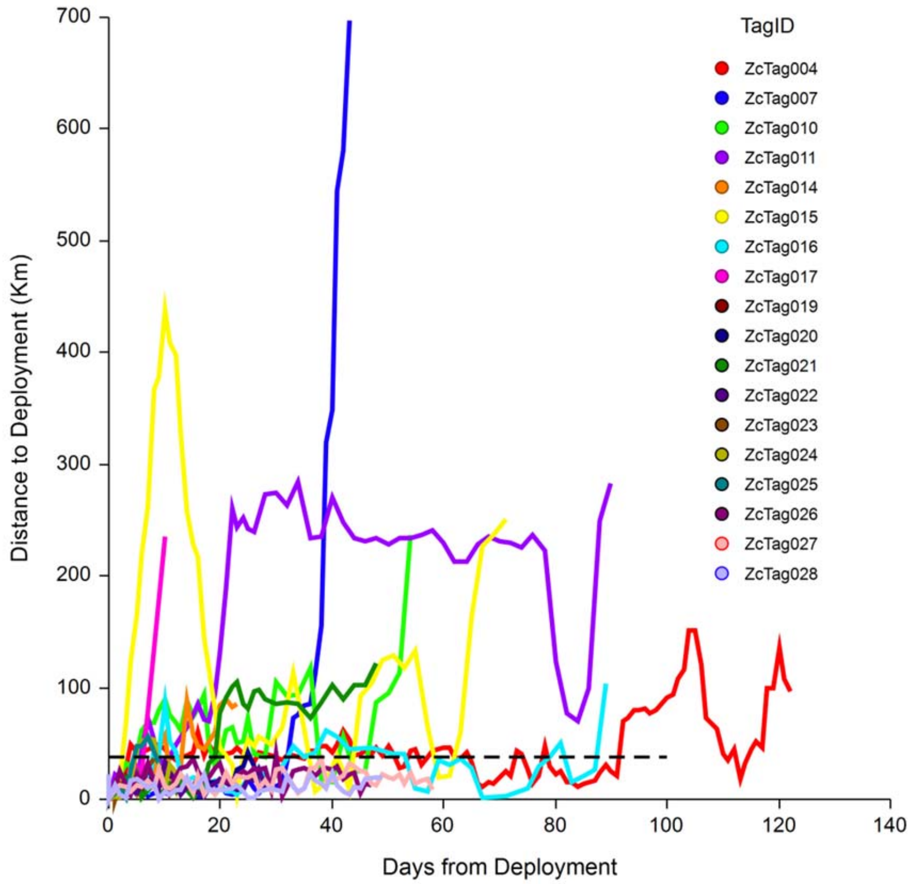


Figure 3. Daily distance to tag deployment location. The grand mean distance to tagging (38 km) is represented by the dashed black line. Despite large extra-regional movements by a few whales, most returned to, or remained within, the San Nicolas Basin. The one individual which traveled the furthest away (*Zc*Tag07) was an adult male.

Overall, 91% of all *Zc* locations fell within the boundaries of the SOCAL Range Complex. For whales tagged on SOAR, 57.1% of all their locations were within the boundaries of that range (Table 11) and 67.5% within the San Nicolas Basin (Figure 4). For the two whales tagged in the Catalina Basin, 20% and 27% of locations were within the Shore Bombardment Area (SHOBA) or 3803XX, respectively (Figure 4, Table 11). With sufficient sample sizes, telemetry data combined with photo-ID could allow for a more detailed assessment of disturbance by operation type and operation area, and may allow for accounting of more realistic take numbers for this species in this region.

Table 10. Sighting histories of six tagged *Zc* that were photographed in more than one year.

TagID	Age	Sex	Sightings	Years First to Last Sighting
ZcTag004	Adult	Female	3	3.45
ZcTag015	Adult	Female	3	0.53
ZcTag017	Adult	Female	2	1.69
ZcTag023	Adult	Male	2	2.76
ZcTag025	Adult	Male	4	5.42
ZcTag028	Sub-Adult	Unk	2	0.79

Table 11. Percentage of locations within designated ranges and geographic basins. Group means (sd) are in bold at the bottom of the table.

TagID	n	% of Locs in SoCal Complex	% of Locs in SOAR	% Locs in SHOBA	% Locs in 3803XX	% Locs in San Nicolas	% of Locs in Santa Cruz Basin	% Locs in Catalina Basin
ZcTag004	350	100%	25%	0%	0%	33%	0%	2%
ZcTag007	179	92%	67%	0%	0%	72%	0%	0%
ZcTag010	172	49%	12%	0%	0%	31%	62%	1%
ZcTag011	175	41%	14%	0%	0%	23%	0%	0%
ZcTag014	81	80%	58%	0%	0%	73%	16%	1%
ZcTag015	292	79%	17%	0%	0%	33%	17%	0%
ZcTag016	195	99%	56%	0%	0%	72%	1%	0%
ZcTag017	43	100%	51%	0%	0%	63%	0%	0%
ZcTag019	50	100%	96%	0%	0%	100%	0%	0%
ZcTag020	122	98%	79%	0%	0%	93%	0%	0%
ZcTag021	132	100%	37%	0%	0%	43%	0%	0%
ZcTag022	65	100%	85%	0%	0%	94%	0%	0%
ZcTag023	24	100%	100%	0%	0%	100%	0%	0%
ZcTag024	41	100%	61%	2%	0%	85%	0%	0%
ZcTag025	33	100%	61%	0%	0%	64%	0%	0%
ZcTag026	194	100%	0%	19%	15%	0%	0%	92%
ZcTag027	255	100%	0%	1%	10%	1%	0%	98%
ZcTag028	178	100%	96%	0%	0%	100%	0%	0%
Overall average		**89%**	**38%**	**2%**	**2%**	**47%**	**7%**	**17%**

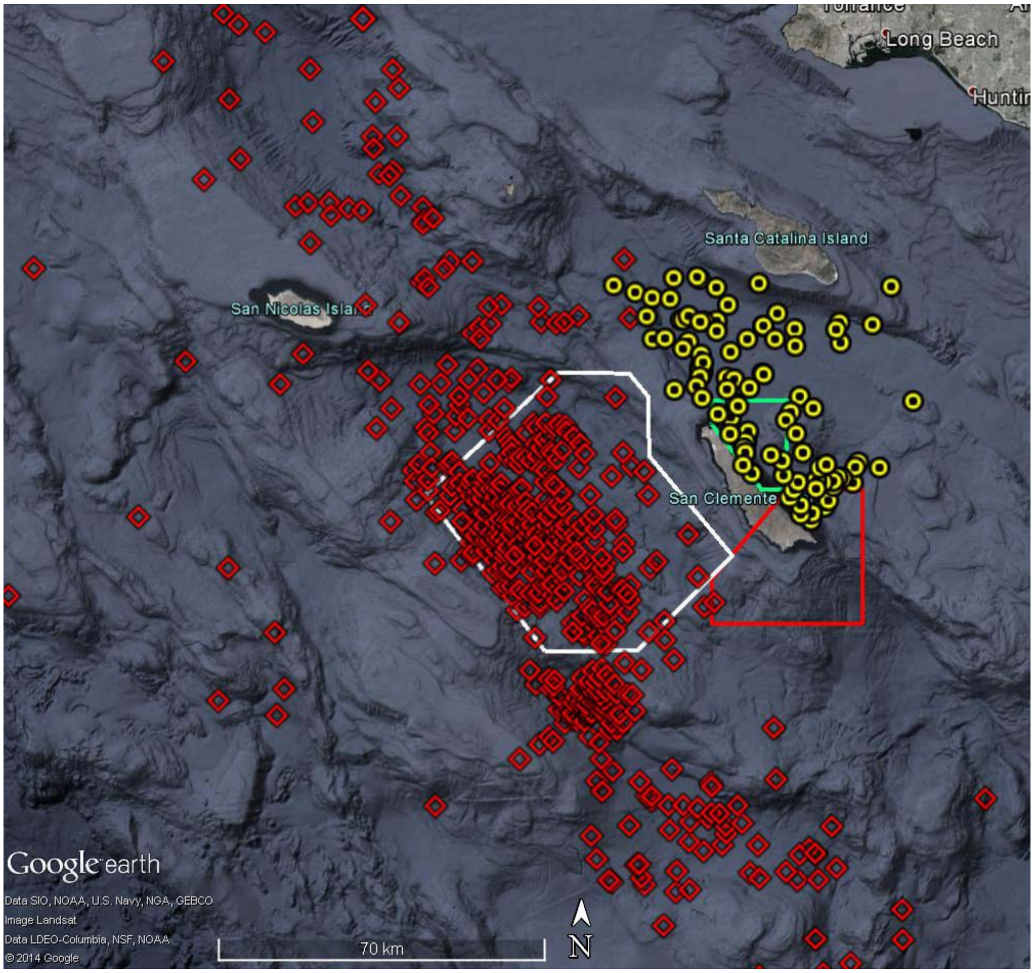


Figure 4. Daily positions of tagged *Zc* in the SCB, with animals tagged on SOAR denoted by red diamonds and animals tagged in the Catalina Basin by yellow circles. Movements between the San Nicolas Basin (where SOAR is located) and the Catalina Basin were very rare. SOAR is outlined in white, SHOBA in red, and 3803XX in green.

Dive Behavior-- Cuvier's Beaked Whales

Schorr *et al.* (2014) summarized the first 3732 hours of dive data from eight *Zc* tagged as part of this work in 2010-2012. Since then, eight additional dive-reporting tags were deployed in 2013 and 2014, bringing this total body of data to 8248 hours. The pressure sensor on *Zc*Tag027 failed somewhere between 0.6-3 days into a 57.8 day deployment, yielding erroneous dive depth data; removal of affected data reduced the dataset to 6891 hours. Prior to tag deployments in 2014, we beta-tested a new land-based Argos receiving station on San Clemente Island called a MOTE (Wildlife Computers, Redmond, WA). The MOTE dramatically improved Argos data throughput, yielding a 422% increase in total messages received over Argos satellites alone, including a 56% increase in total behavior log data.

Uncorrupted messages were received from as far away as 67km. This unit is currently on loan from Wildlife Computers as a test unit, and we will work to secure funding to purchase one for permanent installation on San Clemente Island. This increase in data throughput for animals on SOAR will significantly improve future analyses of *Zc* behavior in relation to MFAS use, which has been complicated by discontinuity in the behavioral records from earlier tags that relied solely on Argos satellites to offload data.

Two extended periods without reported MFAS use were identified during tag deployments: one in January 2011 and the next in January 2014. Though SPORTS was not queried for the month of December prior to deployment dates, the SCORE range operations center reported that sonar use is very rare in the last week of December due to holidays and an annual range maintenance closure which typically extends 1-2 weeks into January. This provides up to three weeks without sonar use at SOAR in late December-early January for most years. The first reports of MFAS use in the SoCal Range Complex in 2011 occurred on January 11, and in 2014 MFAS use was not reported until January14. There were three tags active prior to the date of the first MFAS in January 2011, and five in January 2014. Real-time monitoring of the SOAR hydrophone array (as part of M3R-associated fieldwork) occurred during daylight hours for all dates except 10 January 2011 and 12-13 January 2014, thus providing secondary confirmation that tagged animals were not exposed to sonar for most of the overlapping dates. The behavioral records from these eight whales provided a total of 633 hours of dive data in the absence of reported MFAS.

Basic dive parameters during the sonar-free period are summarized for each tagged whale in Table 12A. The group mean deep dive depth was 1430 m (sd = 205, n = 8) and the deepest dive was 1940 m. These values are very similar to the larger dataset when whales were within the San Nicolas Basin, and continue to suggest that deep dive depth is primarily driven by bottom depth. Group mean deep dive duration was 63.5 min (sd = 6.5, n = 8), slightly shorter than the group mean of the larger dataset (67.4 min). The longest dive during the sonar-free period was 103.8 min. While still very long, it was considerably shorter than the longest dive of 137.5 min (Schorr *et al.* 2014). Despite the relative brevity of these datasets (0.6-9.3 consecutive days per whale), considerable variability in deep dive duration was again evident both within and between individuals (Figure 5, Table 12A). The group mean surfacing duration was slightly longer in the non-exposed data, though most individual median values spanned a similar range to those presented in Schorr *et al.* (2014), so this difference appears to primarily have been driven by the unusually long surfacing bouts seen in ZcTag014 (Table 12B).

The group mean IDDI was 102.6 min (sd = 12.3, n =6), with a total range across all whales of 21.6-244.2 min (Table 12). This average was virtually identical to the group mean IDDI for the larger data which included sonar exposures (Schorr *et al.* 2014). The maximum IDDI captured during this period (244.2 min) was, however, much shorter than the maximum in the data that included sonar use (431.1 min). Individual deep dive rates were higher in the sonar-free dataset (group mean of 0.36 dives/hr versus 0.30 dives/hr), though this difference was heavily influenced by the brief and highly fragmented record from ZcTag014. Excluding this whale's data resulted in a group mean deep dive rate of 0.34 dives/hr in the sonar-free period, or about 8 deep dives per day, as in the larger dataset. The general similarity in the average IDDI and deep dive rates in the absence of sonar to those seen in the larger dataset collected both with and without sonar supports two suggestions in Schorr *et al.* (2014): that *Zc* in this region appear to conduct fewer foraging dives each day than animals in other regions (Baird *et al.* 2006, Tyack *et al.* 2006); and that factors other than sonar exposure are likely driving these regional differences. However, even the slight increase in deep dive rate seen here, particularly when taken with the much lower maximum IDDI in the absence of sonar, supports the suggestions that some sonar exposures can cause measurable disruptions in foraging behavior (DeRuiter *et al.* 2013, Schorr *et al.* 2014). If these disruptions occur often enough, they may decrease overall foraging rates for whales that preferentially use SOAR.

Table 12. Summary of diving behavior during an extended period without the use of MFAS. Values are presented by individual median (range), with the group mean (sd) across individuals in bold at the bottom.

A. Diving parameters.

Whale ID	Days without MFAS	Deep Dives *n*	Deep Dives *Depth (m)*	Deep Dives *Duration (min)*	Shallow Dives *n*	Shallow Dives *Depth (m)*	Shallow Dives *Duration (min)*
ZcTag014	3.5	12	1536 (1232-1808)	59.7 (38.9-66.7)	38	272 (66-560)	14.3 (2.0-23.5)
ZcTag015	4.1	29	1424 (960-1904)	58.1 (42.1-82.3)	141	296 (56-816)	20.3 (1.1-30.9)
ZcTag016	4.0	25	1200 (1104-1584)	71.1 (49.6-84.8)	114	280 (96-544)	22.4 (5.2-40)
ZcTag024	9.3	44	1552 (872-912)	70.2 (38.2-103.8)	183	272 (58-624)	21.9 (2.6-52.1)
ZcTag025	8.2	29	1680 (1104-1840)	71.7 (53.7-92.5)	127	256 (68-592)	21.4 (5.3-51.9)
ZcTag026	6.2	56	1200 (880-1328)	55.0 (42.3-83.4)	265	228 (54-656)	17.4 (3.9-30.9)
ZcTag027	0.6	5	1200 (1136-1264)	61.6 (60.5-73.5)	31	208 (94-656)	16.2 (10.6-30.7
ZcTag028	2.3	19	1648 (1328-1712)	60.4 (51.4-86.7)	105	256 (66-704)	16.5 (2.8-37.5)
Total		**219**	**1430 (205.2)**	**63.5 (6.5)**	**1004**	**259 (28.6)**	**18.8 (3.1)**

B. IDDI, deep dive rate (deep dives per hour of data received), and surfacing durations.

Whale ID	Inter-Deep Dive Intervals *n*	Inter-Deep Dive Intervals *# Shallow Dives*	Inter-Deep Dive Intervals *Duration (min)*	*Deep dives per hr*	Surfacings *n*	Surfacings *Duration (min)*
ZcTag014	5	1 (0-3)	32.6 (3.7-67.6)	0.49	50	2.7 (1.0-22.7)
ZcTag015	24	5 (1-9)	116.2 (29.3 - 194.6)	0.35	170	2.4 (0.5-34.9)
ZcTag016	23	5 (1-7)	132.3 (61.4 - 195.9)	0.31	139	2.4 (0.6-38.1)
ZcTag024	30	4 (1-8)	103.3 (21.6 - 235.7)	0.34	226	2.1 (0-57)
ZcTag025	20	4 (1-7)	117.2 (27.4 - 244.2)	0.33	153	2.0 (0-56.4)
ZcTag026	55	5 (0-9)	101.5 (28.7 - 178.3)	0.38	320	1.8 (0.5-73.2)
ZcTag027	5	6 (4-9)	116.6 (63.3-178.7)	0.33	36	1.6 (0.9-8.5)
ZcTag028	19	5 (2-10)	101.2 (40.5 - 228.5)	0.35	123	1.9 (0-21.1)
Total	**181**	**4.4 (1.5)**	**102.6 (30.2)**	**0.36 (0.06)**	**1217**	**2.10 (0.25)**

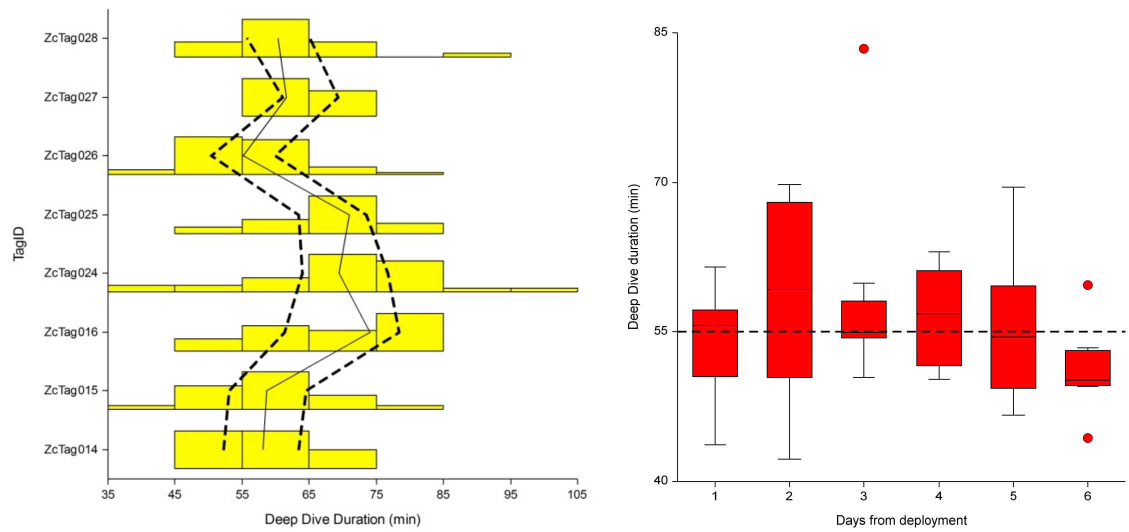


Figure 5. Deep dive durations during time periods with no reported MFAS use. ***Left:*** Histogram plot of deep dive duration by individual, demonstrating the variability in this behavior both within and between individuals. The solid black line connects the median value for each individual; the dashed lines connect the upper and lower 25^{th} percentiles. ***Right:*** Box plot of deep dive duration by day for *Zc*026, the whale with the most extensive sonar-free dataset. The red dots represent extreme outliers in this whale's data.

Satellite Telemetry-- Fin Whales

Fifty-six fin whales were tagged at SCORE from 2008–2014 (Appendix II). Two tags did not transmit and one tag provided no locations. Median transmission duration was 20 days (range = 1-240), and tags provided a mean of 6.1 (sd = 2) locations per day. During summer and spring, with just one exception tags were predominantly deployed in offshore waters of the bight. Fall and winter deployments occurred more broadly on whales encountered from 4-139 km from the mainland (Figure 6).

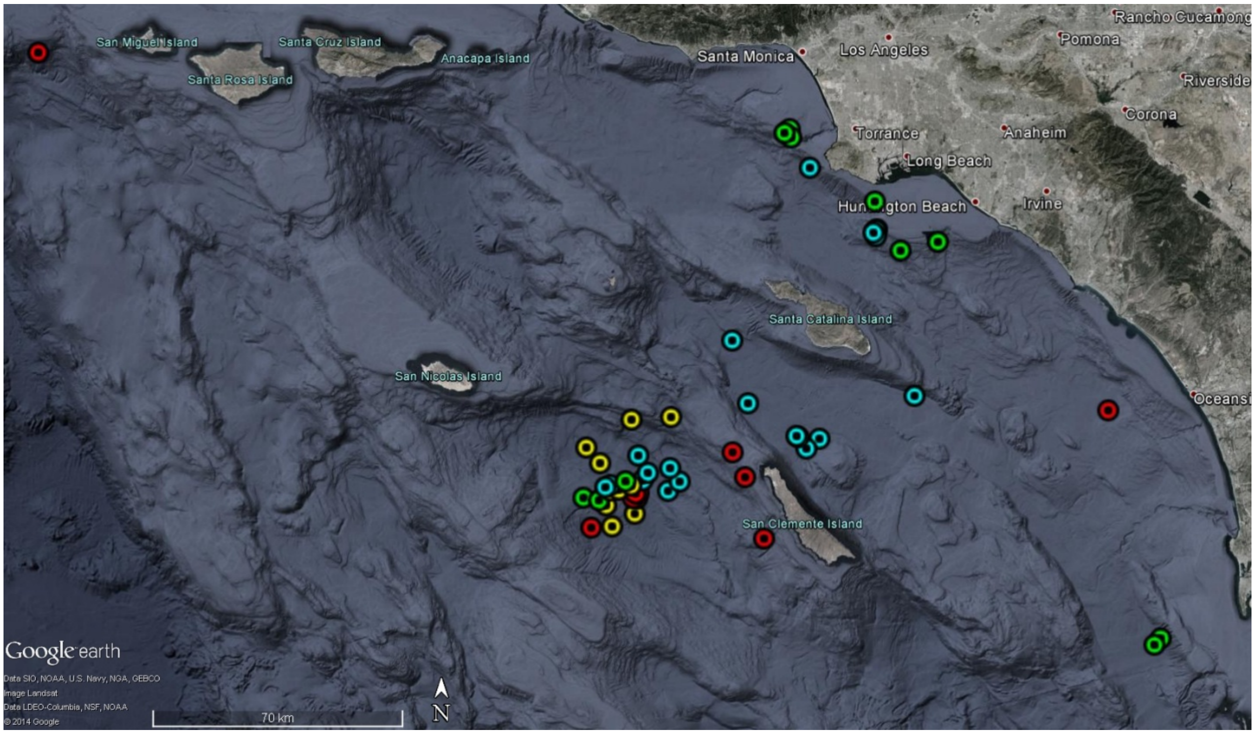


Figure 6. Fin whale tag deployment locations by season. Summer = red, Fall = green, Winter = blue, Spring = yellow.

Movements and Habitat Use-- Fin Whales

A plot of the best daily locations for all tagged whales demonstrates extensive use of the northern half of the San Nicolas and Catalina basins, the inshore waters near Palos Verdes, and west of the shelf extending northwest from San Nicolas Island-- most of which are encompassed by several military training ranges or designated shipping lanes (Figure 7). It is important to note that many tags were deployed in these same areas, and thus there is some bias inherent in the data. However, at a minimum the data demonstrate that whales encountered in these areas tend to remain there for days or weeks at a time. To reduce the effect of tagging location bias introduced by shorter duration tags, we plotted only the tracks of nine tags which transmitted for more than 50 days (Figure 8). These tracks suggest prolonged and repeated use of the SCB is common among *Bp* tagged there. While several whales left the SCB, most either had returned or were en route back when the tag stopped transmitting. The whale that traveled furthest during its deployment had returned to within 300 km of the tagging location before the tag stopped transmitting (Figure 9). The whale with the longest transmission duration (240 days) made limited excursions to the north and south, but returned quickly and spent the majority of its transmission time in the SCB (Figure 10). The maximum distance between the southernmost (central Baja California) and northernmost (Cape Mendocino, California) locations from the entire dataset was 2070 km. The longest round-trip excursion from the SCB was 79.4 days, and one tagged whale left the SCB for 72 days before the tag stopped transmitting. Most excursions were much shorter in duration, and occurred both in summer and fall (Figure 8). Group median distance to tagging location was just 34 km (max range by individual = 5 – 1088, n = 53). The median rate of travel between locations within the SCB was 0.7 km/hr, which was significantly slower than the rate of travel outside the SCB (1.4 km/hr) (Kruskal-Wallis Multiple comparison, Z-value = 4.2, $p < 0.001$).

Taken in combination with photo-identification data that document the same individuals using the SCB repeatedly both within and between years, the movement patterns and habitat use captured by these tags, even those of shorter duration, support the theory that the SCB represents a core use area for a sub-population of whales along the US West Coast.

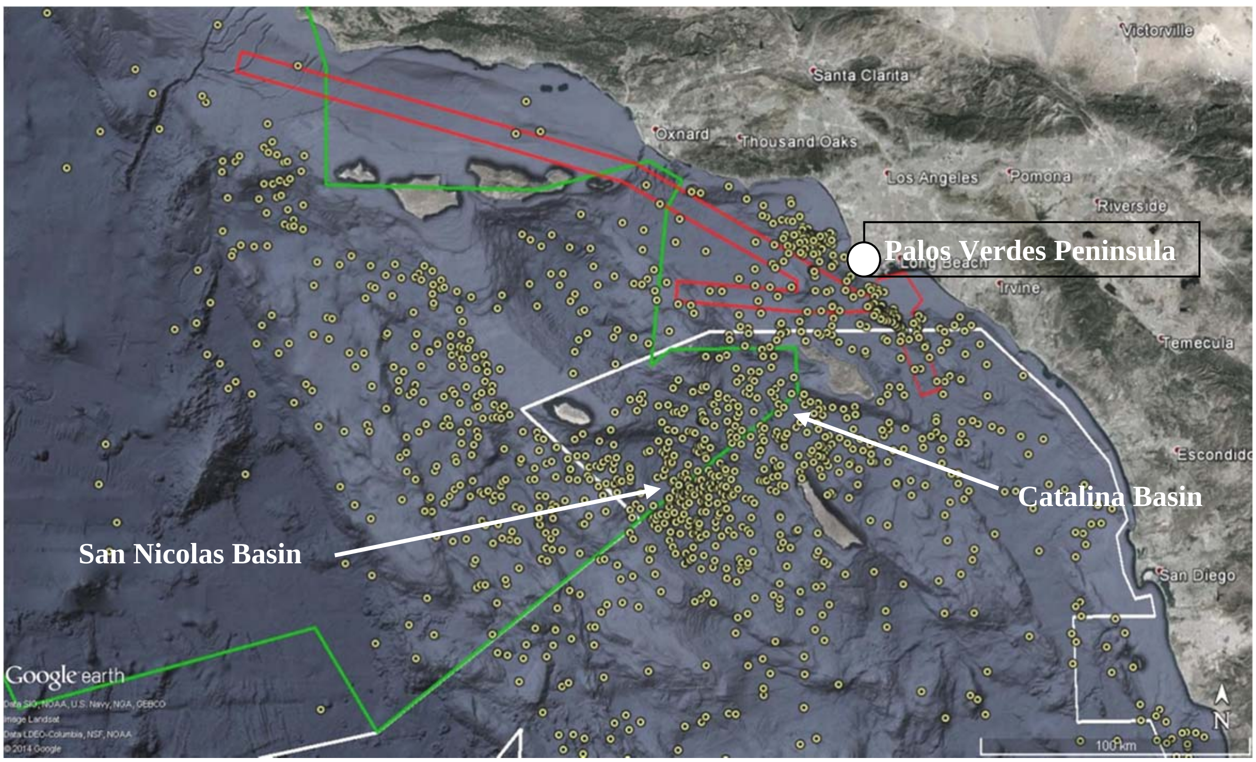


Figure 7. One location per day for each tagged fin whale off Southern California. The Pt. Mugu Sea Range is outlined in green, the SoCal Range Complex is outlined in white.

Of the 9136 locations received, a total of 8061 (88%) were within either the SoCal Range Complex (50%) or the Pt. Mugu Sea Range (38%) (Figure 7). (See Appendix II for individual details.) A total of 13% of all locations were within the SOAR range boundary. To minimize the bias associated with tagging location, from 15 individuals we sub-sampled 2318 locations that were received more than 30 days after the deployment date. Of these locations, 68% were within one of the range complexes, though the total proportion of locations within the range varied widely by individual (Appendix II). These results suggest that individual fin whales are spending extended periods within the boundaries of the training ranges of the SCB, regardless of where within the Bight they were tagged.

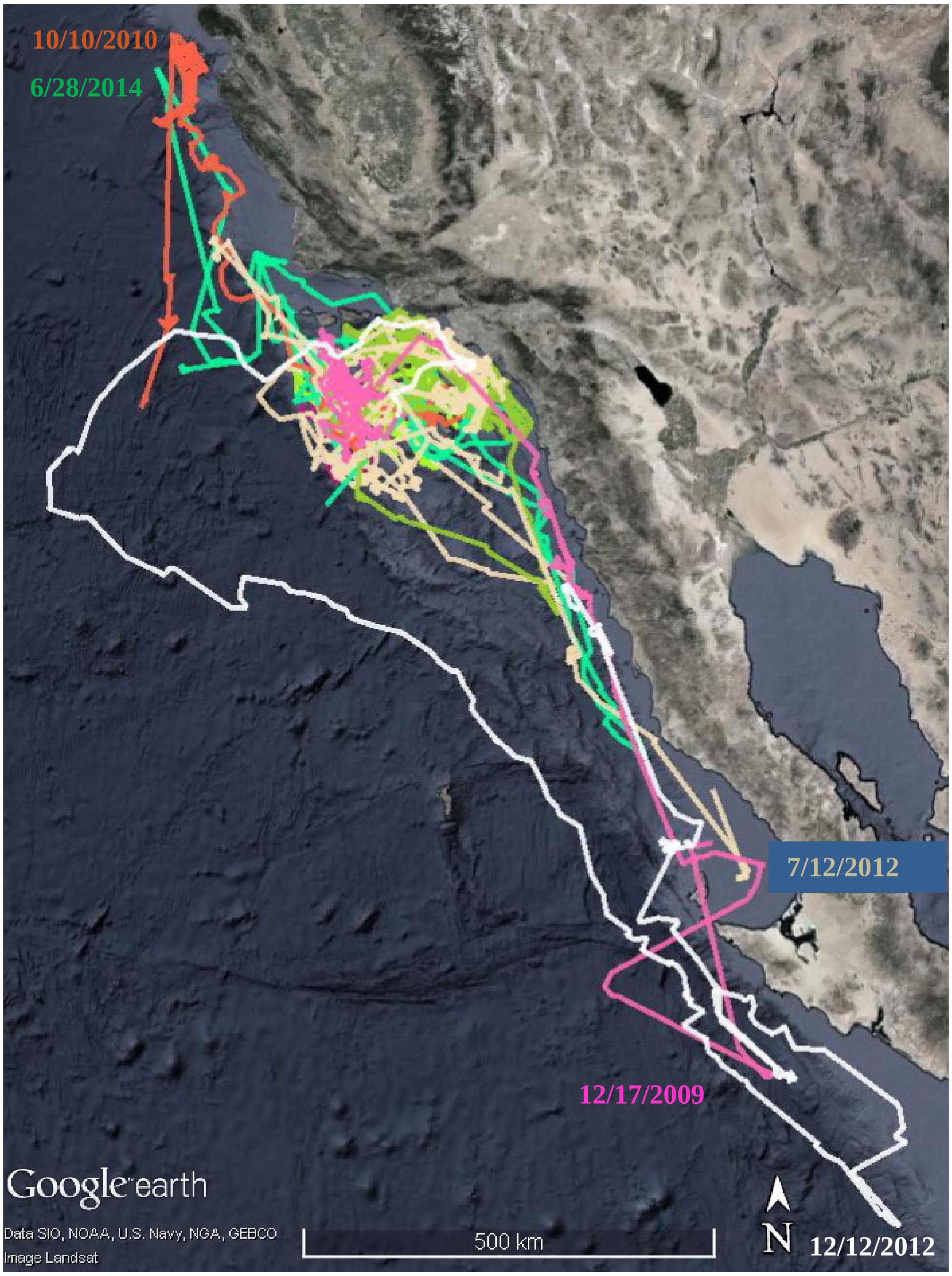


Figure 8. Map showing the tracks of the 9 tags that transmitted for more than 50 days. While some animals left the SCB, traveling both to the north and south, most whales returned, or were on their way back, to the SCB before their tags ceased transmitting. Dates of the northern- and southern-most locations for selected tracks are labeled with the corresponding track color.

The group mean water depth used was 1033 m, though this varied seasonally (Table 13). This indicates that although fin whales have been documented feeding on prey relatively shallow in the water column (Croll *et al.* 2001), they preferentially do so in much deeper water habitat. Given the overlap of distribution with training ranges and shipping lanes, this may help explain why fin whales are one of the most frequently ship-struck large whales in the stranding record along the US west coast (Redfern *et al.* 2013): as ships move further offshore into deeper waters away from areas like the Santa Barbara Channel, both ship speeds and sea states generally increase, both of which decrease the likelihood that transiting vessels can detect and/or avoid whales. It also suggests that the carcasses of fin whales struck by large ships are much less likely to be observed, since mortally injured whales are likely to sink in very deep water far from shore, and that actual collision rates may be considerably higher than for blue whales, which are more likely to be struck in shallower nearshore habitat and thus be recovered or observed. Coupled with the percentage of time spent above 20m water depth (see diving behavior below), fin whales could be at even greater ship strike risk in the SCB.

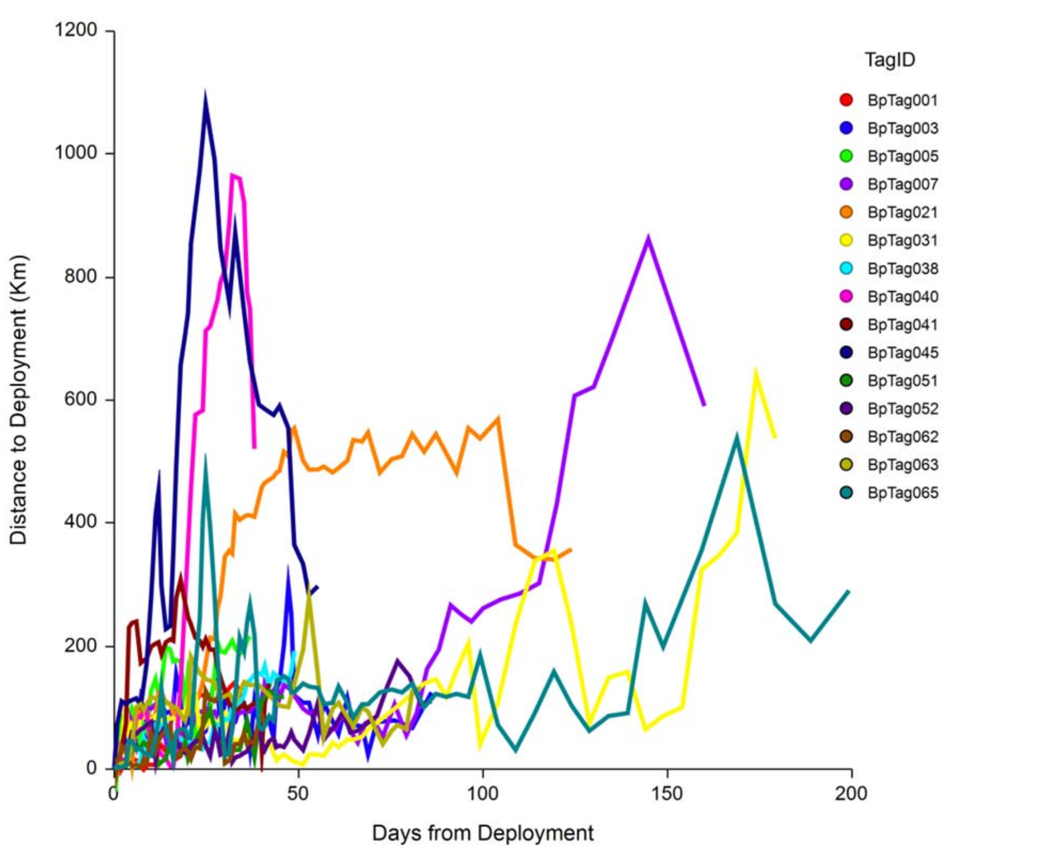


Figure 9. Distance to deployment location by day for fifteen tags that transmitted for more than 30 days. Only four individuals traveled more than 600 km from the tagging location, with all four heading back towards the tagging location when the tag ceased transmitting.

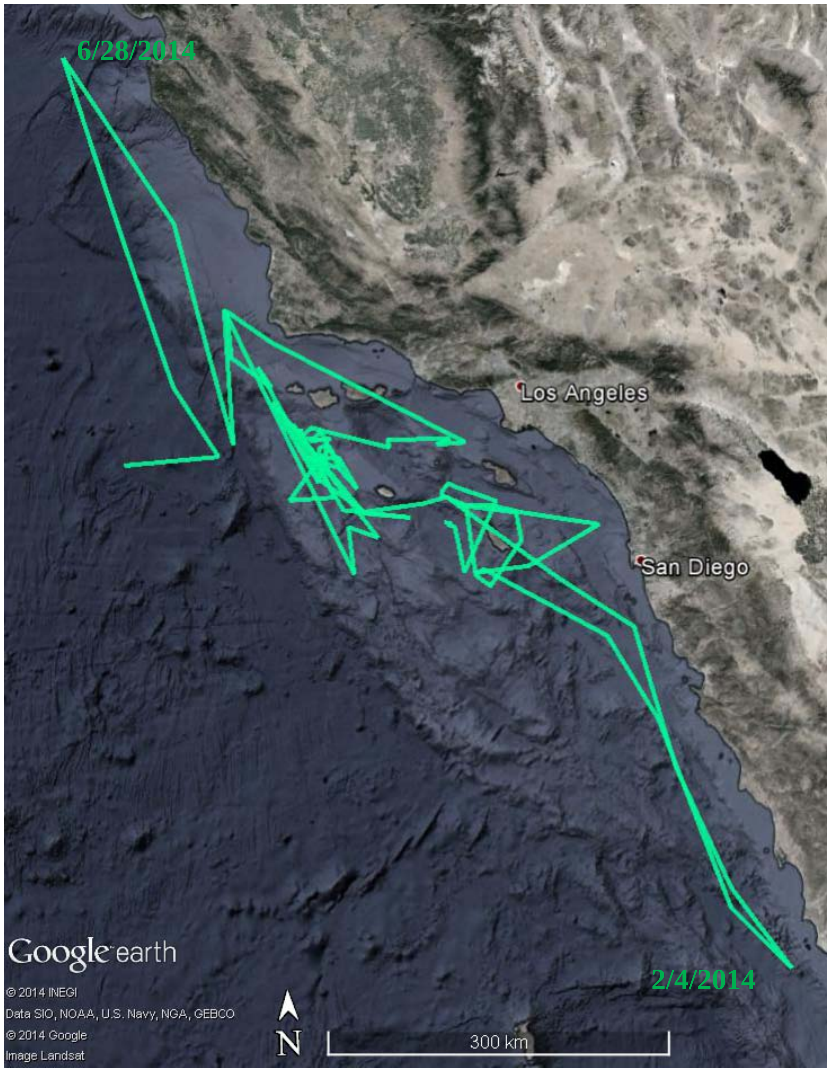


Figure 10. A 220-day track of a fin whale tagged on the SOAR range in January 2014, with the northern- and southern-most points labeled with the date of the position estimate.

Seasonality-- Fin Whales

From historical whaling records (Mizroch *et al.* 2009), visual surveys (e.g., Forney & Barlow 1998, Douglas *et al.* 2014), and more recently through passive acoustic monitoring (Sirović *et al.* 2013), fin whales have been documented year-round in the SCB. However these methods provided little insight as to the identity of the whales in the area, and were too coarse to provide data on seasonal changes in distribution within the region.

The seasonal distribution of *Bp* tag deployments is summarized in Table 13. The sub-sample of data used to assess changes in the seasonal distribution of *Bp* in the SCB (restricted to locations between N32.2^{o} and N34.6^{o} latitude) contained the following number of locations by season: Spring = 2021, Summer = 1653, Fall = 1006, Winter = 2865. A clear seasonal distribution shift was evident, with whales tending to aggregate along the mainland coast and in the northern Catalina Basin in the fall and winter, and disperse throughout the outer waters of the SCB and west of the continental shelf in spring and summer (Figures 11 and 12), though several areas were used year-round. The northern portion of the San Nicolas Basin was one such important area. There was no significant difference in distance to the mainland between fall and winter; but the differences between winter/fall and summer/spring were highly significant (Bonferroni multiple comparison test, $p = 0.001$, all Z values > 30.4), with whales much further offshore during the summer and spring (Table 13).

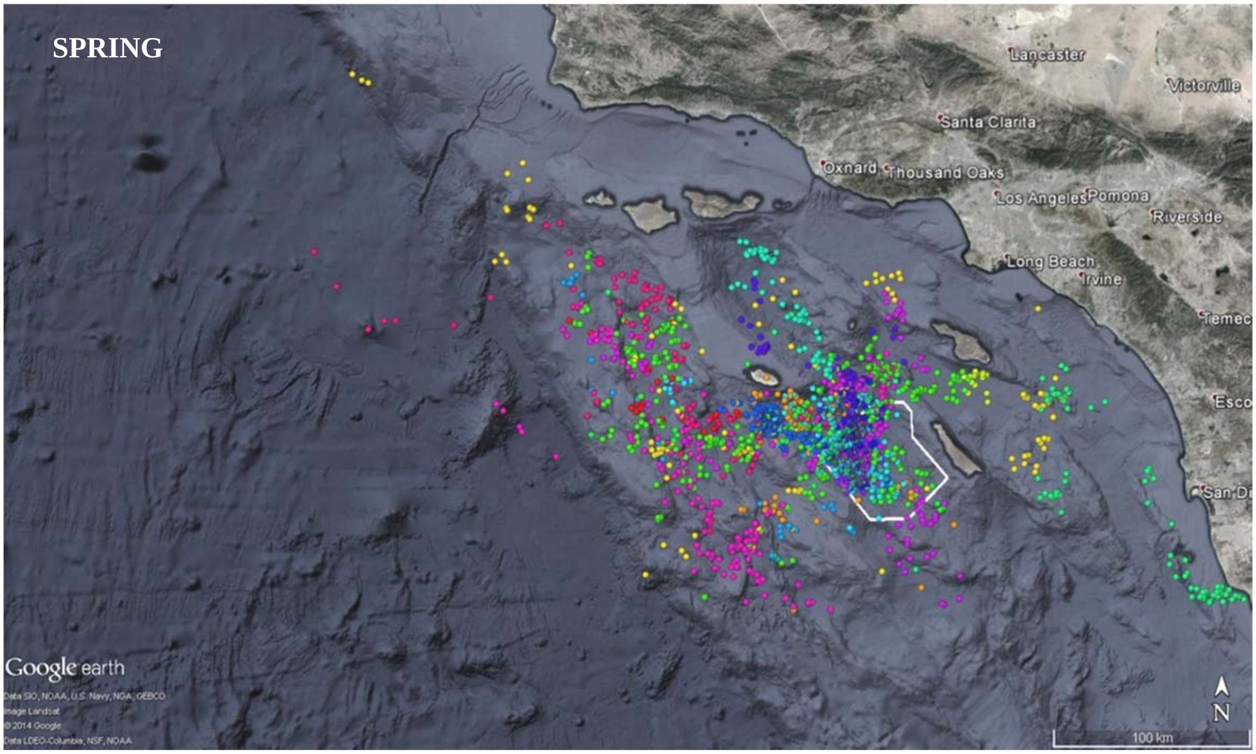
Use of nearshore waters in fall and winter appears to be a recent development, based on our own personal experience, conversations with local tour operators and naturalists (many of whom have routinely conducted winter whale watching trips for gray whales for many years), and the CalCOFI study, which included year-round survey effort throughout the SCB. Sighting data from CalCOFI surveys in 2004-2008 suggested *Bp* were further from shore in fall than summer (the seasons with the highest number of sightings in that study), and closest to the mainland in spring, though the mean distance to the mainland was still 66 km (Douglas *et al.* 2014). Both this and another earlier line-transect study documented *Bp* in the SCB during the winter months (Forney & Barlow 1998, Douglas *et al.* 2014), and in both cases whales were closer to shore in winter than in summer or fall. However, these observations were based on a limited number of sightings. In our study, encounters with dense winter aggregations of fin whales resulted in the largest number of tags deployed in any one season (20). Both earlier studies used data collected prior to 2009 (Forney & Barlow 1998, Douglas *et al.* 2014), whereas almost all tags included here were deployed in 2009 or later. Tags were not deployed in the same seasonal ratio across all years: most of the fall locations were from 2008-2009, and most winter locations from 2012-2014, so there is some potential bias introduced by annual variation in whale distribution (Figure 13). This apparent increase in nearshore habitat use during the fall and winter beginning in 2009 could be due to an increase in abundance (as suggested by Moore & Barlow 2011) and a subsequent increase in observations throughout their existing range, an eastward shift in habitat use by the existing population not unlike that observed for blue whales off central California in the early 1980s (Calambokidis *et al.* 1990), or a combination of these factors. However, when combined with results of photo-identification (see above) and the previous abundance estimate from Barlow & Forney (2007), the data more strongly suggest an inshore shift in distribution than an increase in abundance.

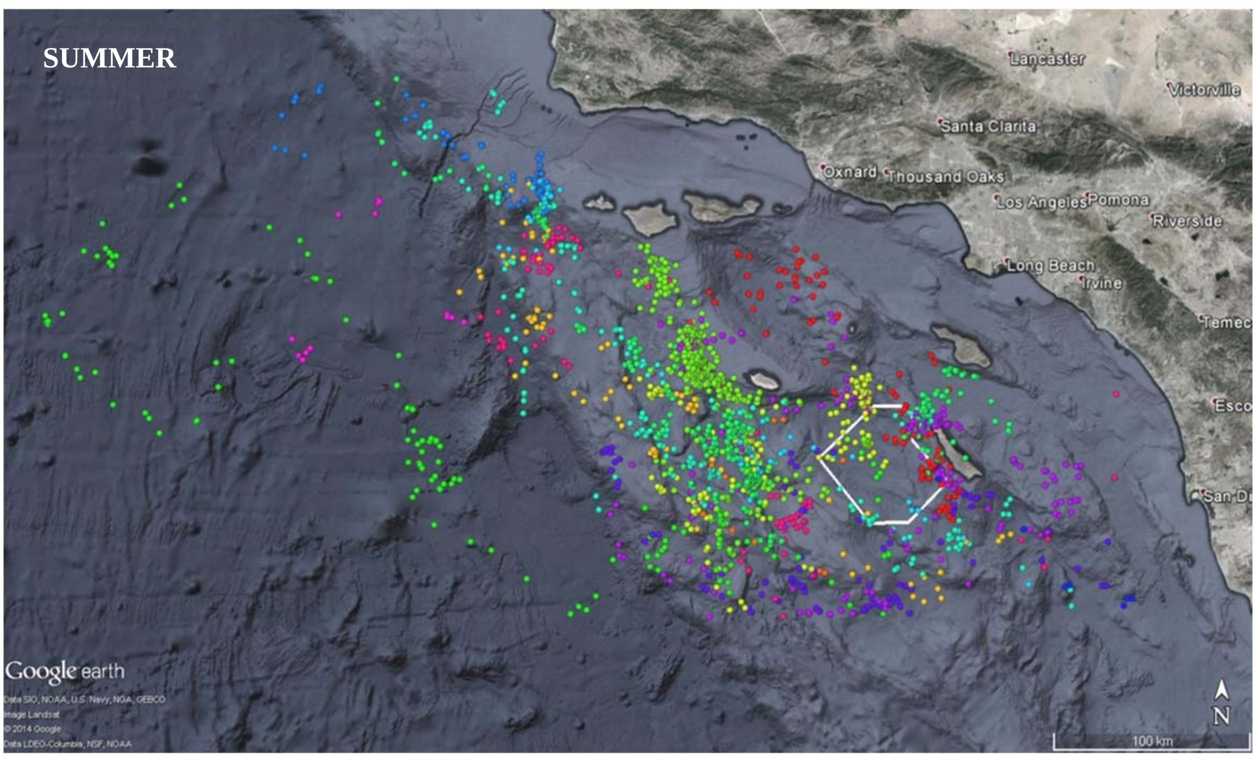
It is interesting to note that even with this inshore shift, only two whales entered the Santa Barbara Channel during the winter, and they were present there for just six total days. This may be driven by habitat preferences for this species-- elsewhere in the SCB tagged whales tended to use deeper habitat than is available in the Santa Barbara Channel (Table 13). It is also possible that fin whales have not historically used this area, which is heavily used by blue whales during the productive summer months (Fiedler *et al.* 1998), but that fin whales may begin to shift into this area during winter in the future if sufficient prey occur. Larger blue whales are the dominant baleen whale species in spring and summer months throughout much of the habitat that was used by tagged fin whales in fall and winter. Blue whales in the SCB are part of a broad Eastern North Pacific population, and historically have tended to arrive in the SCB in late spring but shift north out of the area as summer progresses and productivity increases further up the California coast (Calambokidis *et al.* 2009). While the two species are known to co-occur in the spring and summer, the larger-scale *Bp* seasonal shifts may represent a form of seasonal niche partitioning for these ecologically similar species, with whales from the smaller, local fin whale sub-population shifting into coastal habitat during periods where it is not dominated by blue whales.

In addition to seasonal changes in distribution, there were also significant seasonal differences in the rate of daily displacement. Minimum rate of travel was calculated between the Best Daily Locations (Douglas *et al.* 2012) for each individual, using only locations that were received between12 and 36 hours apart to avoid spuriously high or low values. Median rates were highest in the fall (1.1 km/hr, range = 0.04 – 9.1) followed by summer (1.0 km/hr, range =0.04 – 6.8), with both seasons significantly higher than winter and spring (Bonferroni multiple comparison, Z-values > 2.66). Winter rates of movement were the lowest with a median of 0.6 km/hr (range = 0.03 – 6.8), reflecting the stability and limited range used by winter aggregations. This may be because whales are drawn to these areas for both feeding and social reasons.

Table 13. Summary of locations received and habitat used by season. Values are group medians, with the range of individual medians in parentheses. Four locations that plotted on land were excluded from this analysis.

Season	Start Date	End Date	No. locs.	Depth (m)	Distance to land (km)	Distance to Mainland (km)
Summer	21-Jun	20-Sep	2373	1153 (13 - 4654)	41 (0 - 271)	103 (7 - 278)
Fall	21-Sep	20-Dec	1402	868 (5 - 4431)	22 (0 - 390)	38 (1 - 390)
Winter	21-Dec	20-Mar	3082	889 (15 - 4531)	18 (1 - 139)	51 (1 - 163)
Spring	21-Mar	20-Jun	2275	1223 (32 - 4508)	36 (2 - 304)	111 (2 - 304)





<u>Figure 11.</u> *Bp* locations by season, with each individual represented by a unique color. ***Top:*** Position estimates from 19 tagged whales during spring. ***Bottom:*** Position estimates from 15 tagged whales during summer.

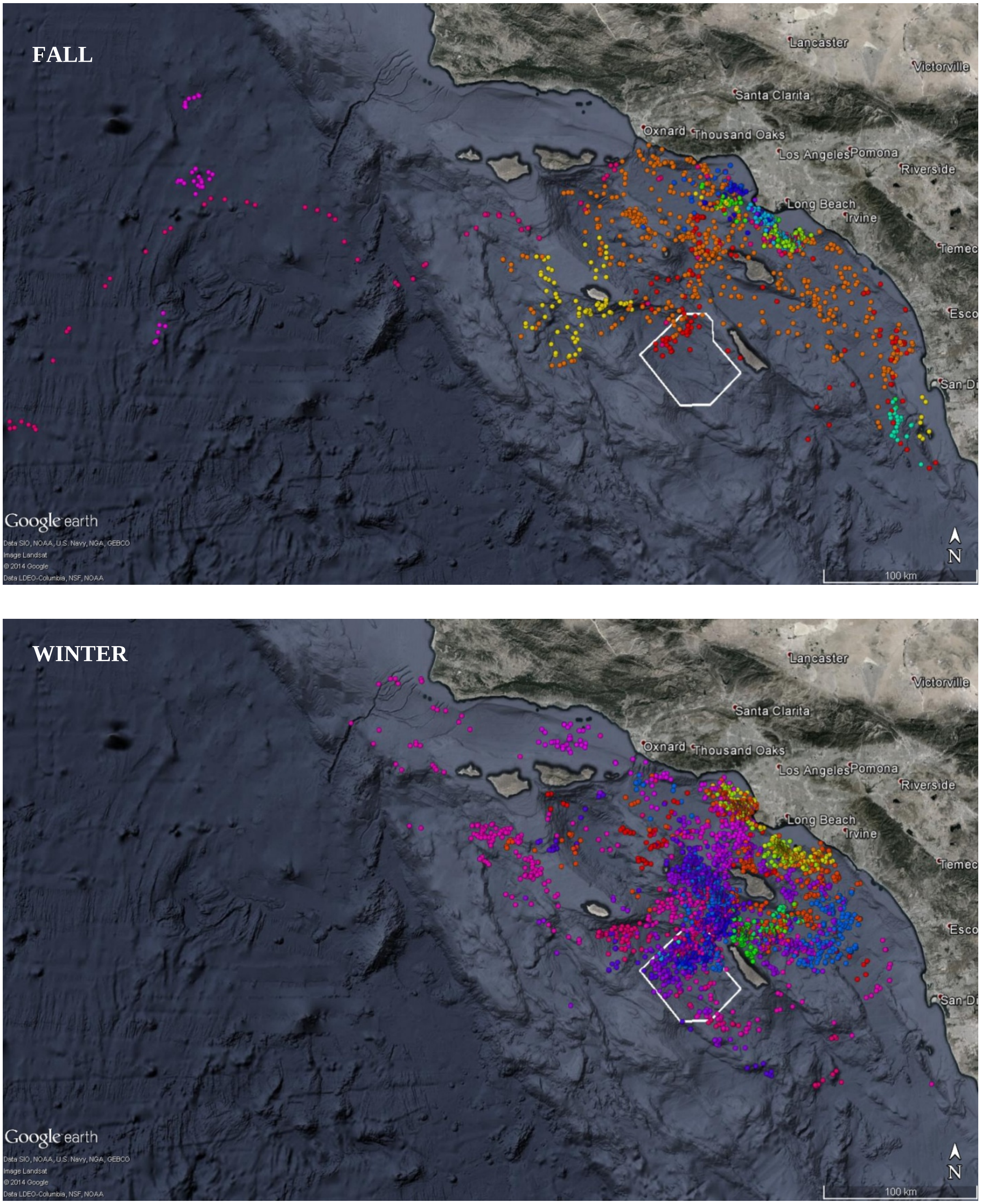


Figure 12. *Bp* locations by season, with each individual represented by a unique color. ***Top:*** Position estimates from 13 tagged whales during fall. ***Bottom:*** Position estimates from 21 tagged whales during winter.

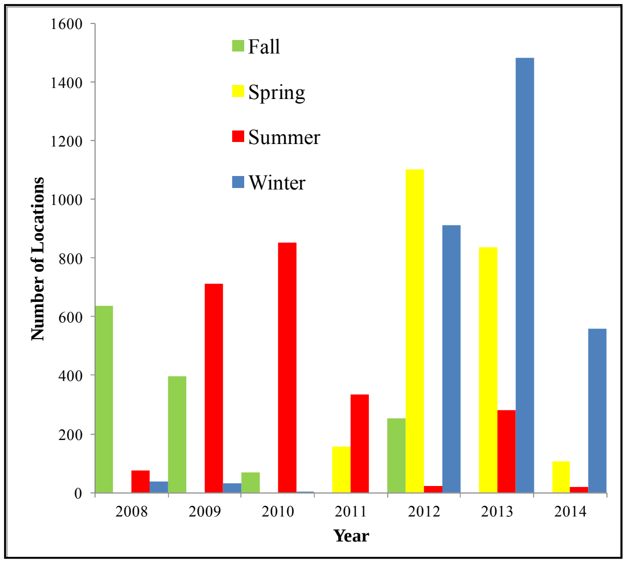


Figure 13. Seasonal distribution of fin whale locations by year.

Diving Behavior–– Fin Whales

1974 hours of dive data were collected from nine whales, all of which were tagged in winter or spring (Table 14). Overall group mean dive depth was just 45 m, with a mean duration of 4.2 minutes. Fin whales suction cup-tagged in the same region during August 2003 had an average dive depth of 248 m and duration of 7.0 minutes (Goldbogen 2006). The shorter and shallower dives from our dataset may indicate a seasonal shift toward feeding in the upper water column during these months, or may reflect an increase in time spent engaged in behavior other than foraging. Regardless of the reason, data from these whales indicate that on average they spend 71 percent of their time above 20 m, which is within one body length of the surface for most whales and could increase their susceptibility to ship strikes. Further tag deployments in other times of the year are warranted to address possible seasonal differences in diving behavior.

Table 14. Primary dive parameters by individual, with the group mean (sd) across individuals in bold at the bottom. Individual table values are medians, with ranges in parentheses. Dives were recorded as submergences below 20 m for more than 30 sec, with the start and end time marked as the animal passed 5 m depth.

TagID	Date tagged	Hrs Dive Data	Number of dives	Dive Depth (m)	Dive Duration (min)	% time <20m depth
BpTag050	1/5/2013	87	510	29 (20-248)	2 (0.5-14.5)	73%
BpTag051	1/8/2013	505	1672	35 (20-288)	4.5 (0.5-15.5)	74%
BpTag057	3/23/2013	13	35	52 (20-132)	5.1 (0.8-9.1)	78%
BpTag058	3/23/2013	258	1215	38 (20-376)	3 (0.5-13.8)	73%
BpTag059	3/29/2013	114	383	39 (20-264)	4.7 (0.5-14.9)	72%
BpTag060	3/29/2013	92	620	38 (20-312)	3 (0.6-13.1)	58%
BpTag061	3/29/2013	102	350	66 (20-272)	4.5 (0.5-10.0)	75%
BpTag063	5/19/2013	396	1539	69 (20-392)	4.8 (0.5-12.4)	70%
BpTag066	1/10/2014	407	1198	38 (20-304)	6.2 (0.5-21.8)	68%
		1974	**7522**	**45 (14.2)**	**4.2 (1.3)**	**71% (57%)**

Concluding Remarks

Prior to the initiation of M3R-associated surveys at SOAR in 2006, it was unknown if any beaked whales would be found on or near such a heavily used training range. Through the continuation of these surveys in recent years, we now know that despite the frequent use of MFAS, *Zc* are present year-round in the San Nicolas Basin. It also appears that these whales are part of a small, fairly localized population with basin-specific core use areas. We have collected the most extensive body of behavioral data from this species in existence, and have expanded the known limits of their diving capabilities (Schorr *et al.* 2014). With continued effort, we will build on these photographic and behavioral data sets to address the question of what effect anthropogenic activity might be having on this small population. In combination with a growing collection of sonar use data, we will be able to document how whales in this population react to the training exercises they must routinely experience. Even more importantly, our demographic data have the potential to document changes in population size and structure that might occur as a result of cumulative sonar exposure. Few other types of study can provide this level of validation to theoretical behavioral and population models.

This work has also provided the first detailed look at fin whale population structure off the US West Coast, and particularly Southern California. We have shown through both photo-ID and telemetry that whales encountered off Southern California tend to remain off Southern California, undergoing seasonal distribution shifts but remaining largely within a fairly limited latitudinal range. There is increasing evidence that these whales also form a fairly small, localized sub-population, whose range overlaps heavily with military training areas and shipping lanes, increasing the level of impacts they are subjected to relative to whales outside this region.

Beyond these focal species, we have collected photographic, genetic, and telemetry datasets from this relatively inaccessible region to support collaborative studies and also potential future work with a range of species that occur there. Chief among these are killer whales-- including the extended satellite tracks from "offshore" ecotype whale-- Risso's dolphins, bottlenose dolphins, and sperm whales.

Ultimately, this work has provided valuable data products in and of itself, and it will continue to form the basis of future work in an area that is likely to be of considerable interest to the military and environmental managers for years to come.

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Appendix I

CRC Fin Measurement Protocol v. 29 September 2014

Prepared by Erin Falcone, Erin Keene, and Eric Keen. Cascadia Research Collective.

Goal: Obtain a series of consistent dorsal fin measurements and use these to create a unique set of proportions to describe each whale/dolphin in the catalog. Use these proportions to objectively rank fins during comparison by similarity in shape. These ranks will function in conjunction with species-specific filters to prioritize subsets containing the most likely match.

Tools: Dorsal fin images, ***ImageJ*** (and Java runtime environment), ***MS Access*** and a copy of the CRC Digital Catalog system for the species of interest.

Before you begin, you will need to install the program ***ImageJ*** on your computer. You can download the program from http://rsbweb.nih.gov/ij/download.html, if needed. You will need the Java runtime environment to run it. So if you don't already have that on your computer, you can also get that from the same website. Run the executable file or files to install the program.

To expedite fin measurement in *ImageJ*, install macros at the end of this document as follows:

a. Copy macro text and open ImageJ.
b. On the top toolbar, navigate: Plugins > Macros > StartUp Macros…
c. Scroll to the bottom of the window that pops up.
d. Paste the copied text to the bottom of this file.
e. In this window, go File > Save
f. Close the window, then close ImageJ.

As you work with the various functions we are using, *ImageJ* will remember many menu settings you change, even between work sessions. Before you measure your first ever image (or after reinstalling *ImageJ*), you need to configure the results window which stores measurements as you take them so that it matches the table structure into which you will be pasting them. In the menu bar, go to "Analyze/Set Measurements...." Check only the boxes for "Display label" and "Add to overlay" and set Decimal places to 1.

1) Open ImageJ.
   a) It will appear as a small floating toolbar somewhere on your desktop.
2) Open your first image for this work session.
   a) The keyboard shortcut for this command is **Crtl+O**; or use the menu bar to go to "File/Open..."
   b) Browse to the folder that contains the images with which you will be working.
3) Open an image to be measured from the Images list.

4) Rotate the image until the base of the fin is as close to horizontal as you can reasonably get it by eye.
   a) Select the line tool.
   b) Click-and-drag a line across the base of the dorsal fin, from where the dorsal begins to where it ends. Be as accurate as you can possibly be.
   c) Click the "L" key. The image should automatically rotate so that the fin's base is now horizontal.
   d) If you are not happy with the rotation, draw a new line and type "L" again. Adjust the angle until you are happy with the rotation, then click OK.
   e) Note that the arch of the whale's back can interfere with your perception of level. Really try to level the base of the fin to horizontal, not necessarily the topline of the back.
5) Prepare the image view for measuring.
   a) Use the + or – keys to zoom in or out. Or select the Magnifier in the toolbar to zoom into the fin, if needed.
      i) Left click zooms in, right click zooms out.
      ii) When the image zooms, it will center over where your cursor is positioned. If you position it well, you can zoom without having to reposition the image after you are done.
   b) Select the Hand tool if you need to reposition the fin in the window.
6) **Measure *1***, the vertical distance from the posterior fin tip to the caudal peduncle. NOTE: If you have a triangular or disfigured fin, find the point at which the leading edge transitions to the trailing edge as best you can. This may be well inside the insertion of the trailing edge. It's ok, as long as we are consistent in the definition.
   a) Select the Straight Line tool from the toolbar.
   b) Place the cursor at center of the most posterior tip of the fin.
      i) Note that as you move the cursor around the image, the status window below the toolbar will tell you the exact coordinates to help you fine tune your placement-- though this doesn't have to be perfect.
   c) Press **Shift** and hold down the left mouse button to draw a vertical line that meets the top of the back below.
      i) Shift forces the line to be vertical or horizontal.
   d) Press **Ctrl+M** to log the measurement to the results window and **Ctrl+D** to draw the line.
7) Before you move the Line Tool, **mark the control points** along this line by typing the "Q" key.
8) **Measure *2***, the horizontal distance from the top of ***1*** to the leading edge of the fin. NOTE: For triangular or disfigured fins, this distance may be zero. In this case, just place the cursor on the top point without dragging, and skip to step c below.
   a) Place your cursor on the **bottom** point of ***1,*** until it turns to a little hand.
   b) Press **Shift** and hold down the left mouse button to pivot this line horizontally around the top point until it meets the leading edge.
   c) Press **Ctrl+M** to log the measurement to the results window and **Ctrl+D** to draw the line.
9) **Measure *3***, the horizontal distance from the **upper quarterline point** to the **trailing edge.** NOTE: For triangular or disfigured fins, this distance may be zero, or technically negative. In this case, just place the cursor on the midpoint of the vertical without dragging, and skip to step c below.
   a) Place the cursor on the mark you made for the upper quarterline.
   b) Press **Shift** and hold down the left mouse button to drag this line horizontally until it meets the trailing edge of the fin.

c) For fins that are very triangular or distorted, and for which the trailing edge is actually behind the vertical (relative to the leading edge), just place the cursor on the midpoint of ***1***, and left click once.

d) For fins that have a notch at the point where the line meets the trailing edge, please estimate where the edge would have been were the notch not there, to the best of your ability. We will be integrating notches into the system a different way, and this should just group fins into their overall shape. This way you can still search whales in the historical data that may have gained a notch later.

e) Press **Ctrl+M** to log the measurement of ***3***, and if you opted for the single point on a triangular fin, this length should be zero.

10) **Measure *4***, the horizontal distance from the upper quarterline mark to the **leading edge.**

a) Place the cursor on the end point of ***3*** at the trailing edge until it becomes a little hand.

b) Press **Shift** and hold down the left mouse button to drag this line horizontally until it meets the leading edge of the fin.

c) Press **Ctrl+M** to log the measurement and **Ctrl+D** to draw the line.

11) **Measure line pairs *5-6 and 7-8***, as seen in Figure 14, in the same fashion as you did for 3-4.

12) **Select and then Cut** (**Ctrl+X**) **measurements *1-8*** from the Results window and paste them into the MS Access Digital Catalog you will be using to compare them using the functions provided in the database.

a) Verify that you got all measurements and that they are in the correct order. For the vast majority of fins, measurements 3, 5, and 7 will be much shorter than the others. If this pattern is not true, verify that you measured in the correct order.

13) **Save a cropped copy of the image you just measured** for future reference, and go to the next image in the folder.

a) Switch to the Rectangular Selection tool in the tool bar.

b) Draw a box around the fin and the measurement grid you just drew over it.

c) Click **Ctrl+Shift+X** to crop this image.

d) Click **Ctrl+S** to save a copy to the Measured folder inside the Historical folder. (Use the Default filename provided; it will convert it to a TIFF file.)

e) Click **Ctrl+Shift+O** to open the next image in line. (Or just **Ctrl+O** to open the browser window, from which the next on the list can be opened, if you are not working through images sequentially.)

f) Go to Step 4 above and repeat for the next image to be measured.

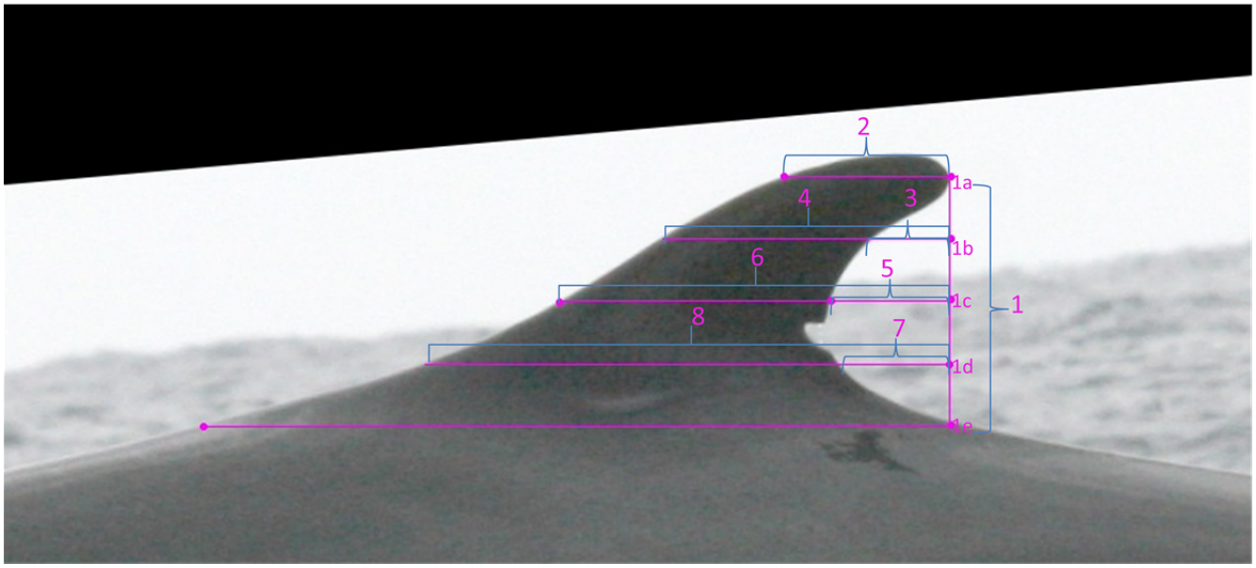

Figure 14. Measurement layout.

ImageJ Macros (See above for instructions for installation.)

```
//The macro "Leveler" is used to quickly rotate an image such that the base of a dorsal fin is horizontal.
// Before running the macro, draw a line across the base of the fin.
macro "Leveler [l]" {
// Get the angle of this line with the picture's horiztonal;
//run("Draw");
run("Measure");
theta =getResult("Angle");

if(theta > 90) {
theta = -(180-theta);
}

if(theta < -90) {
theta = (180+theta);
}

// Increase canvas size;
h = getHeight();
w = getWidth();
w = w*1.3;
h = h*4;
run("Canvas Size...", "width=&w height=&h position=Center zero");
```

```
run("Clear Results");

// Open the rotate dialog box and rotate by that angle;
run("Rotate...  ", "angle=&theta grid=8 interpolation=Bilinear fill=TRUE englarge=TRUE");
//setTool("hand");
setLineWidth(1);
}



// The macro "quarters" draws dots along a line selection
// at the beginning, 1/4 way point, 1/2 way point, 3/4 point, and ending of the line.

macro "quarters [q]" {

getLine(x1,y1,x5,y5,width);

// Make oval size and line width a function of line length
if(x1==x5) {
orient = "v";
length = abs(y5-y1);
ovwit = (length/(length/3))+1;
}

if(y1==y5) {
orient = "h";
length = abs(x5-x1);
ovwit = (length/(length/3))+1;
}

y2 = y1 + ((y5-y1)/4);
y3 = y1 + ((y5-y1)/2);
y4 = y5 - ((y5-y1)/4);

x2 = x1 + ((x5-x1)/4);
x3 = x1 + ((x5-x1)/2);
x4 = x5 - ((x5-x1)/4);

// Adjust coordinates for the fillOval function
adj = ovwit/2;
x1 = x1 - adj;
x2 = x2 - adj;
x3 = x3 - adj;
x4 = x4 - adj;
```

```
x5 = x5 - adj;

y1 = y1 - adj;
y2 = y2 - adj;
y3 = y3 - adj;
y4 = y4 - adj;
y5 = y5 - adj;

setTool("brush");
setColor("magenta");
setLineWidth(3);
fillOval(x1,y1,ovwit,ovwit);
fillOval(x2,y2,ovwit,ovwit);
fillOval(x3,y3,ovwit,ovwit);
fillOval(x4,y4,ovwit,ovwit);
fillOval(x5,y5,ovwit,ovwit);
setLineWidth(1);
setTool("line");
}
```

Appendix II. *Bp* deployment summaries, using all locations that passed the Argos Filter.

TagID	Date Tagged	Tag Type	Trans-mission duration (Days)	Number of Locations	Mean Number of Locations per Day (sd)	Cumulative horizontal distance traveled (km)	Median distance to Deployment Location (Max) (km)	Percent Locations inside SOCAL Range Complex	Percent Locations inside Pt. Mugu Range	Percent Locations inside SOAR	Percent inside SCORE--Locations >30 days	Percent inside Pt. Mugu--Locations >30 days
*Bp*Tag001	8/08/2008	Spot5	35.0	87	3.2 (1.8)	781	31 (143)	64.4	40.2	26.4	0.0	100.0
*Bp*Tag002	10/22/2008	Spot5	26.2	136	5.0 (3.2)	1983	90 (422)	75.0	11.8	20.6	N/A	N/A
*Bp*Tag003	10/23/2008	Spot5	86.8	581	9.2 (2.8)	5527	86 (297)	52.2	31.3	1.9	49.1	25.3
*Bp*Tag004	7/24/2009	Spot5	12.1	10	2.0 (0.7)	200	58 (74)	60.0	60.0	10.0	N/A	N/A
*Bp*Tag005	7/25/2009	Spot5	37.2	90	2.5 (1.6)	1607	129 (215)	25.6	72.2	2.2	0.0	100.0
*Bp*Tag006	7/25/2009	Spot5	22.1	176	7.7 (1.9)	1224	60 (151)	57.4	68.8	10.2	N/A	N/A
*Bp*Tag007	7/25/2009	Spot5	160.1	501	6.3 (2.0)	5014	94 (862)	13.2	74.7	0.6	11.1	67.2
*Bp*Tag008	7/25/2009	Spot5	19.1	129	6.5 (2.5)	1323	212 (414)	24.0	51.9	6.2	N/A	N/A
*Bp*Tag009	11/12/2009	Spot5	11.1	52	4.3 (2.8)	295	10 (25)	25.0	0.0	0.0	N/A	N/A
*Bp*Tag010	11/13/2009	Spot5	6.1	31	4.4 (2.1)	208	29 (51)	0.0	0.0	0.0	N/A	N/A
*Bp*Tag011	11/16/2009	Spot5	10.1	1	N/A	5	3 (5)	100.0	0.0	0.0	N/A	N/A
*Bp*Tag012	11/16/2009	Spot5	2.8	23	5.8 (3.3)	110	16 (50)	30.4	0.0	0.0	N/A	N/A
*Bp*Tag013	11/21/2009	Spot5	8.1	65	7.2 (3.1)	293	11 (31)	13.8	0.0	0.0	N/A	N/A
*Bp*Tag014	11/22/2009	Spot5	3.1	28	7.0 (2.7)	283	14 (66)	0.0	3.6	0.0	N/A	N/A
*Bp*Tag015	11/23/2009	Spot5	5.0	29	5.8 (2.9)	250	10 (30)	0.0	0.0	0.0	N/A	N/A
*Bp*Tag016	11/24/2009	Spot5	12.2	18	2.3 (1.6)	131	25 (37)	0.0	0.0	0.0	N/A	N/A

TagID	Date Tagged	Tag Type	Trans-mission duration (Days)	Number of Locations	Mean Number of Locations per Day (sd)	Cumulative horizontal distance traveled (km)	Median distance to Deployment Location (Max) (km)	Percent Locations inside SOCAL Range Complex	Percent Locations inside Pt. Mugu Range	Percent Locations inside SOAR	Percent inside SCORE--Locations >30 days	Percent inside Pt. Mugu--Locations >30 days
*Bp*Tag021	6/28/2010	Spot5	124.4	625	8.3 (1.6)	3991	395 (569)	10.1	38.2	0.5	0.0	10.8
*Bp*Tag022	6/28/2010	Spot5	27.3	223	8.0 (2.5)	1814	134 (326)	34.1	66.8	4.5	N/A	N/A
*Bp*Tag026	5/04/2011	Mk10-A	4.3	45	9.0 (7.0)	305	65 (156)	37.8	84.4	15.6	N/A	N/A
*Bp*Tag027	5/04/2011	Mk10-A	1.1	3	1.5 (0.7)	46	25 (42)	66.7	100.0	0.0	N/A	N/A
*Bp*Tag028	5/06/2011	Mk10-A	27.3	110	4.4 (2.6)	909	51 (188)	88.2	46.4	4.5	N/A	N/A
*Bp*Tag029	6/22/2011	Spot5	16.6	84	4.9 (2.0)	1021	169 (405)	42.9	58.3	4.8	N/A	N/A
*Bp*Tag030	6/22/2011	Spot5	28.2	251	8.7 (2.7)	1770	163 (286)	0.0	85.3	0.0	N/A	N/A
*Bp*Tag031	1/20/2012	Spot5	179.2	491	5.9 (3.2)	5783	76 (640)	48.1	0.0	0.4	64.7	0.0
*Bp*Tag032	1/20/2012	Spot5	11.1	61	5.1 (2.9)	351	7 (27)	23.0	0.0	0.0	N/A	N/A
*Bp*Tag033	1/20/2012	Spot5	25.0	127	5.1 (2.4)	605	21 (55)	9.4	0.0	0.0	N/A	N/A
*Bp*Tag034	1/21/2012	Spot5	18.0	93	5.2 (2.3)	475	30 (51)	14.0	0.0	0.0	N/A	N/A
*Bp*Tag035	1/21/2012	Spot5	18.0	119	6.6 (2.6)	669	6 (56)	12.6	0.0	0.0	N/A	N/A
*Bp*Tag036	3/14/2012	Spot5	10.1	51	4.6 (3.0)	273	17 (35)	100.0	0.0	0.0	N/A	N/A
*Bp*Tag037	3/15/2012	Spot5	7.1	39	4.9 (2.2)	228	10 (62)	100.0	12.8	12.8	N/A	N/A
*Bp*Tag038	3/16/2012	Spot5	57.2	383	7.7 (2.5)	2542	62 (195)	65.8	55.6	19.3	7.9	94.3
*Bp*Tag039	3/16/2012	Spot5	2.0	22	7.3 (4.7)	110	18 (32)	100.0	0.0	0.0	N/A	N/A
*Bp*Tag040	3/20/2012	Spot5	38.3	128	3.8 (2.2)	2877	49 (979)	50.8	27.3	31.3	0.0	0.0
*Bp*Tag041	3/20/2012	Spot5	42.2	146	3.7 (2.3)	1823	199 (310)	41.8	5.5	2.7	87.1	19.4

TagID	Date Tagged	Tag Type	Trans-mission duration (Days)	Number of Locations	Mean Number of Locations per Day (sd)	Cumulative horizontal distance traveled (km)	Median distance to Deployment Location (Max) (km)	Percent Locations inside SOCAL Range Complex	Percent Locations inside Pt. Mugu Range	Percent Locations inside SOAR	Percent inside SCORE--Locations >30 days	Percent inside Pt. Mugu--Locations >30 days
*Bp*Tag042	3/20/2012	Spot5	18.1	134	7.1 (2.6)	658	21 (110)	67.2	79.1	26.9	N/A	N/A
*Bp*Tag043	3/21/2012	Mk10-A	23.2	255	11.6 (2.9)	1498	34 (98)	93.3	36.1	64.3	N/A	N/A
*Bp*Tag045	11/17/2012	Mk10-A	55.1	353	9.3 (4.0)	4404	575 (1088)	13.9	11.3	0.3	9.4	0.0
*Bp*Tag046	11/17/2012	Spot5	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
*Bp*Tag047	1/05/013	Mk10-A	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
*Bp*Tag048	1/05/2013	Mk10-A	28.2	322	12.4 (3.3)	1848	47 (113)	95.0	30.1	12.1	N/A	N/A
*Bp*Tag049	1/05/2013	Spot5	4.1	33	6.6 (4.3)	139	11 (35)	100.0	3.0	63.6	N/A	N/A
*Bp*Tag050	1/05/2013	Mk10-A	6.1	72	10.3 (4.8)	271	23 (37)	100.0	1.4	44.4	N/A	N/A
*Bp*Tag051	1/08/2013	Mk10-A	46.2	394	11.3 (4.4)	2373	32 (127)	83.5	39.1	18.0	54.1	49.2
*Bp*Tag052	1/13/2013	Spot5	86.1	482	7.4 (2.6)	3416	47 (178)	83.2	19.7	14.9	60.9	18.8
*Bp*Tag053	1/16/2013	Spot5	22.1	193	8.4 (2.7)	1321	25 (143)	4.7	5.7	0.0	N/A	N/A
*Bp*Tag057	N/A	Mk10-A	13.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
*Bp*Tag058	3/23/2013	Mk10-A	14.2	157	10.5 (2.1)	605	47 (75)	40.1	84.7	16.6	N/A	N/A
*Bp*Tag059	3/29/2013	Mk10-A	10.3	89	8.1 (4.2)	489	15 (29)	100.0	43.8	61.8	N/A	N/A
*Bp*Tag060	3/29/2013	Mk10-A	11.2	100	8.3 (4.4)	606	22 (94)	84.0	75.0	25.0	N/A	N/A
*Bp*Tag061	3/29/2013	Mk10-A	11.1	78	6.5 (3.3)	423	16 (28)	100.0	3.8	96.2	N/A	N/A
*Bp*Tag062	3/30/2013	Spot5	44.3	215	5.2 (2.7)	2058	34 (142)	78.1	45.6	35.8	72.5	29.4
*Bp*Tag063	5/19/2013	Mk10-A	83.2	282	5.8 (2.9)	3074	105 (292)	66.3	43.3	1.1	83.7	17.3
*Bp*Tag064	7/08/2013	Spot5	23.3	203	8.5 (2.4)	2359	78 (308)	77.3	29.6	4.9	N/A	N/A

TagID	Date Tagged	Tag Type	Trans-mission duration (Days)	Number of Locations	Mean Number of Locations per Day (sd)	Cumulative horizontal distance traveled (km)	Median distance to Deployment Location (Max) (km)	Percent Locations inside SOCAL Range Complex	Percent Locations inside Pt. Mugu Range	Percent Locations inside SOAR	Percent inside SCORE--Locations >30 days	Percent inside Pt. Mugu--Locations >30 days
*Bp*Tag065	1/10/2014	Spot5	240.0	557	6.6 (2.6)	6812	177 (578)	44.3	60.3	9.1	3.5	90.4
*Bp*Tag066	1/10/2014	Mk10-A	21.3	157	6.9 (2.7)	1264	125 (219)	94.9	55.4	25.2	N/A	N/A
*Bp*Tag067	8/26/2010	Spot5	20.4	101	4.8 (3.3)	1226	212 (318)	46.5	53.5	0.0	N/A	N/A

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